NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

MSC APOLLO 13 INVESTIGATION TEAM

FINAL REPORT

PANEL 6

RELATED SYSTEMS EVALUATION

Get DRA

VOLUME II
LUNAR MODULE

MAY 1970

MANNED SPACECRAFT CENTER
HOUSTON, TEXAS

MSC APOLLO 13 INVESTIGATION TEAM

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PANEL 6

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Volume II

Lunar Module

Prepared by

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1. INTRODUCTION

A study of LM Related Systems has been conducted by NASA and GAC in support of the Apollo-13 Investigation; this report summarizes the results of that study. Information is presented on the following subsystem elements for both the descent and ascent stages:

- Propulsion and Reaction Control propellant and pressurant tanks
- Oxygen tanks
- Water tanks
- Batteries.

The following major elements comprise the overall study:

- Compilation of basic system descriptive data
- Investigation of all line and system components that could potentially initiate a failure mode similar to that believed to have occurred on Apollo 13
- Evaluation of non-metallic materials that are in contact, or could come in contact, with nitrogen tetroxide (N_2O_4), Aerozine-50 (A-50) or oxygen; some consideration was also given to the possible effects of potassium hydroxide (KOH) spillage from batteries
- Compilation of burst test history on all LM pressure vessels, and determination of the anticipated failure modes in flight
- Computation of the TNT equivalency for each pressure vessel as a function of mission time, and an evaluation of the damage potential from each tank for both explosive and non-explosive failures
- Development of conclusions from the above efforts and recommendations for further action.

2. SYSTEMS DESCRIPTION

2.1 SUMMARY

The LM pressure vessels are located in the Descent Propulsion Subsystem (DPS), Ascent Propulsion Subsystem (APS), Reaction Control Subsystem (RCS) and Environmental Control Subsystem (ECS). The LM batteries are located in the Electrical Power Subsystem (EPS) and the Explosive Devices Subsystem (EDS). Table 2.1-1 summarizes the design parameters of each of the LM pressure vessels and batteries.

The DPS contains four propellant tanks, a supercritical helium tank and an ambient helium tank. Figures 2.1-1, 2.1-2, and 2.1-3 show isometric views of the relative location of the DPS components with respect to the descent stage structure. In the LM-10 and subsequent configuration, the propellant tanks were lengthened. A discussion of mechanical failures which could cause pressure vessel rupture is included in Para. 2.2.

Two propellant tanks and two ambient helium storage tanks are included in the APS. Isometric views of the relative position of APS components with respect to the ascent stage structure are shown in Figures 2.1-4 and 2.1-5. A mechanical failure mode that could cause an APS pressure vessel rupture is discussed in Para. 2.3.

The RCS configuration consists of four propellant and two ambient helium tanks arranged in two identical modules. Figure 2.1-6 shows an isometric view of the relative location of the RCS components with respect to the ascent stage structure. There are no single or double point mechanical failures of the RCS system which would lead to an overpressure condition.

LM-8 and LM-9 ECS oxygen and water sections are composed of three oxygen tanks and three water tanks, two of each are in the ascent stage and the remaining tanks are in the descent stage. Isometric views of the relative position of ECS components with respect to the descent stage and ascent stage structures are shown in Figures 2.1-3, 2.1-7, 2.1-8 and 2.1-9. For reference purposes the ascent stage primary and secondary coolant loops are shown in Figures 2.1-10 and 2.1-11, respectively. In the LM-10 and subsequent configuration an additional oxygen tank and water tank are added to the descent stage. There are no single or double point mechanical failures of the ECS system which would lead to an overpressure condition.

2.1 cont'd

The EPS batteries are the ascent and descent primary batteries, and the EDS batteries are the ascent and descent ED batteries. Figures 2.1-3, 2.1-5 and 2.1-12 show isometric views of EPS and EDS components relative to the descent and ascent structures.

TABLE 2.1-1

PRESSURE VESSEL AND BATTERY DESIGN PARAMETER SUMMARY

PRESSURE VESSEL	BASIC PART MATERIAL	DIMENSIONS DIA. IN.	DIMENSIONS LENGTH IN.	DIMENSIONS WALL THICKNESS LOCATION - IN.	TANK CAPACITY VOLUME	TANK CAPACITY LOAD CAPACITY (LB)	NOP PRESS PSI.	NOP TEMP °F	MDOP PRESS PSI	MDOP TEMP °F	PROOF PRESS PSI	PROOF TEMP °F	DESIGN BURST PRESS PSI	DESIGN BURST TEMP °F	FLIGHT PRED. TEMP °F
DPS Prop. Tanks (Oxid. & Fuel)	6Al-4V Ti STA Post Weld Stress Relieved	51	LM-8 & 9 70.8 LM-10 & Sub. 74.1	Dome: 0.033/0.038 Cyl: 0.065/0.070 Girth Weld: 0.090/0.095 Closure Weld: 0.105/0.110	LM-9: 125.6'³ (two tanks) Oxid or Fuel LM-10: 133.6'³ (Two tanks) Oxid or Fuel	Fuel: 7076 Oxid: 11,342 Fuel: 7,520 (2 tanks) Oxid: 12,004 (2 tanks)	248 PSIG	70	270 PSIG	100	Allison: 360 PSIG GAC PIT LM-6,7, 8,9: 375 PSIG Aerojet LM-10 & Sub. 360 PSIG 436 PSIG	Ambient Ambient Ambient Cryo	405 PSIG	Ambient	< 75
*DPS SHe Tank	5Al-2.5 SN ELI Ti, Post inner shell weld stress relieved	Inner shell: 26.96 Outer shell: 32.91	-	Inner Shell: 0.129/0.135 Outer Shell: 0.031/0.038	5.92 ft³	LM-8: 48 Helium LM-10: 51.2 Helium	400-1550 PSIG	-	1710 PSIG	140°R	Airesh. 2274 PSIG GAC PIT 2274 PSIG	140-200°R 60-70°R	3420 PSIG	140°R	8°R - 540°R
DPS Amb He Tank	6Al-4V Ti STA - Post Weld stress relieved	14.89	-	Shell: 0.064/0.069 Girth Weld: 0.095/0.100	1728 in.³	1.1 lbs. Helium	1640 PSIG	70	1750 PSIG	100	2327 PSIG	100	2625 PSIG	100	45 -90 Prior to use
APS Prop. Tanks (Oxid. & Fuel)	6Al-4V Ti	49.4	-	Shell: 0.032	LM-9 & LM-10 36.4 ft³ (per tank)	Fuel: 2007.8 Oxid: 3217.8	184 PSIG	70	250 PSIG	70	333 PSIG	70	375 PSIG	Ambient	57-99
APS He Tanks	6Al-4V Ti	22.32	-	Shell: 0.198/0.203 Girth Weld: 0.308/0.313	5800 in.³	6.6 Lbs./Tank	3050 PSIG	160	3500 PSIG	160	4650 PSIG	160	5250 PSIG	160	40-82
RCS Prop. Tanks (Oxid. & Fuel)	6Al-4V Ti	12.645 O.D.	Oxid: 38.2 Fuel: 32.2	Dome: 0.017/0.023 Cyl: 0.025/0.030 Girth Weld: 0.038/0.043	Oxid: 4107 in.³ Fuel: 3298 in.³	Oxid: 208 per tank Fuel: 107 per tank	180 PSIG	70	250 PSIG	70	333 PSIG	70	375 PSIG	100	70

*NOTE: ANNULAR VOLUME RELIEVES AT 75 PSI THROUGH PINCH-OFF TUBE

TABLE 2.1-1

(Continued)

PRESSURE VESSEL	BASIC PART MATERIAL	DIMENSIONS DIA. IN.	DIMENSIONS LENGTH IN.	DIMENSIONS WALL THICKNESS LOCATION - IN.	TANK CAPACITY VOLUME	TANK CAPACITY LOAD CAPACITY	NOP PRESS PSI.	NOP TEMP °F	MDOP PRESS PSI	MDOP TEMP °F	PROOF PRESS PSI	PROOF TEMP °F	DESIGN BURST PRESS PSI	DESIGN BURST TEMP °F	FLIGHT PRED. TEMP °F
RCS He Tanks	6Al-4V Ti	12.370	-	Shell: 0.099/0.104 Girth Weld: 0.164/0.169	Unpressurized 910 in.^{3}	1.05 lbs. per Tank	3050 PSIG	70	3500 PSIG	130	4650 PSIG	70	5250 PSIG	130	70
ECS D/S Oxygen Tank	D6AC Steel	21.722 O.D.	-	Shell: 0.123/0.128	5181 in.^{3} @ 2825 PSIA and 70°F	LM-8 & 9: 48 lbs. O_2 LM-10: 96 lbs. O_2 (two tanks)	2690 PSIA	75	3000 PSIA	160	4120 PSIA	70	4500 PSIA	160	44-93
ECS A/S Oxygen Tanks	Inconel 718	11.968 O.D.	-	Shell: 0.029/0.033	866 in.^{3} @ 1000 PSIA and 70°F	4.8 lbs. O_2 (two tanks)	840 PSIA	75	1000 PSIA	160	1370 PSIA	70	1500 PSIA	160	35-80
ECS D/S Water Tank	6061-T6 Aluminum	28.48 O.D.	32.5	Shell: 0.040/0.050 Cone: 0.060/0.070	LM-9: 332 lbs. LM-10: 664 lbs.	LM-9: 265 lbs (NOM) LM-10 (72 hrs) 385 lbs (NOM)	47.3 PSID	70	50 PSID	100	64 PSID	70	96 PSID	70	61-75
ECS A/S Water Tanks	6061-T6 Aluminum	14.54 O.D.	-	Shell: 0.027/0.034 Girth Weld: 0.040/0.045	85 lb. H_2O	85 lbs. H_2O (two tanks)	47.3 PSID	70	50 PSID	100	64 PSID	70	96 PSID	70	39-92
EPS D/S Primary Battery	AZ 31B Magnesium	-	10.15x 9.56x 16.5	Sides: 0.10		7200 cc KOH per battery	3-5 PSIG	-	Rel. Vlv. Op. Cell: 1-11 PSIG Case: 2-8 PSIG		-		10.7 PSIG		
EPS A/S Primary Battery	AZ 31B Magnesium	-	8.06x 5.99x 35.25	Sides: 0.10	-	6500 cc KOH per battery	3-5 PSIG		Rel. Vlv. Op. Cell: 1-11 PSIG Case: 2-8 PSIG		-		10.7 PSIG		

TABLE 2.1-1
(Continued)

PRESSURE VESSEL	BASIC PART MATERIAL	DIMENSIONS			TANK CAPACITY		NOP		MDOP		PROOF		DESIGN BURST		FLIGHT PRED. TEMP °F
		DIA. IN.	LENGTH IN.	WALL THICKNESS LOCATION - IN.	VOLUME	LOAD CAPACITY	PRESS PSI	TEMP °F	PRESS PSI	TEMP °F	PRESS PSI	TEMP °F	PRESS PSI	TEMP °F	
EPS ED Battery	G-10 Epoxy Fiber Glass	-	6.78x 2.75x 3.03	Sides: 0.062	-	240 cc KOH per battery	25-35 PSIG		Rel. Vlv. Op. Cell (Int.): 2 PSIG Case: 25-35 PSIG		-		-		

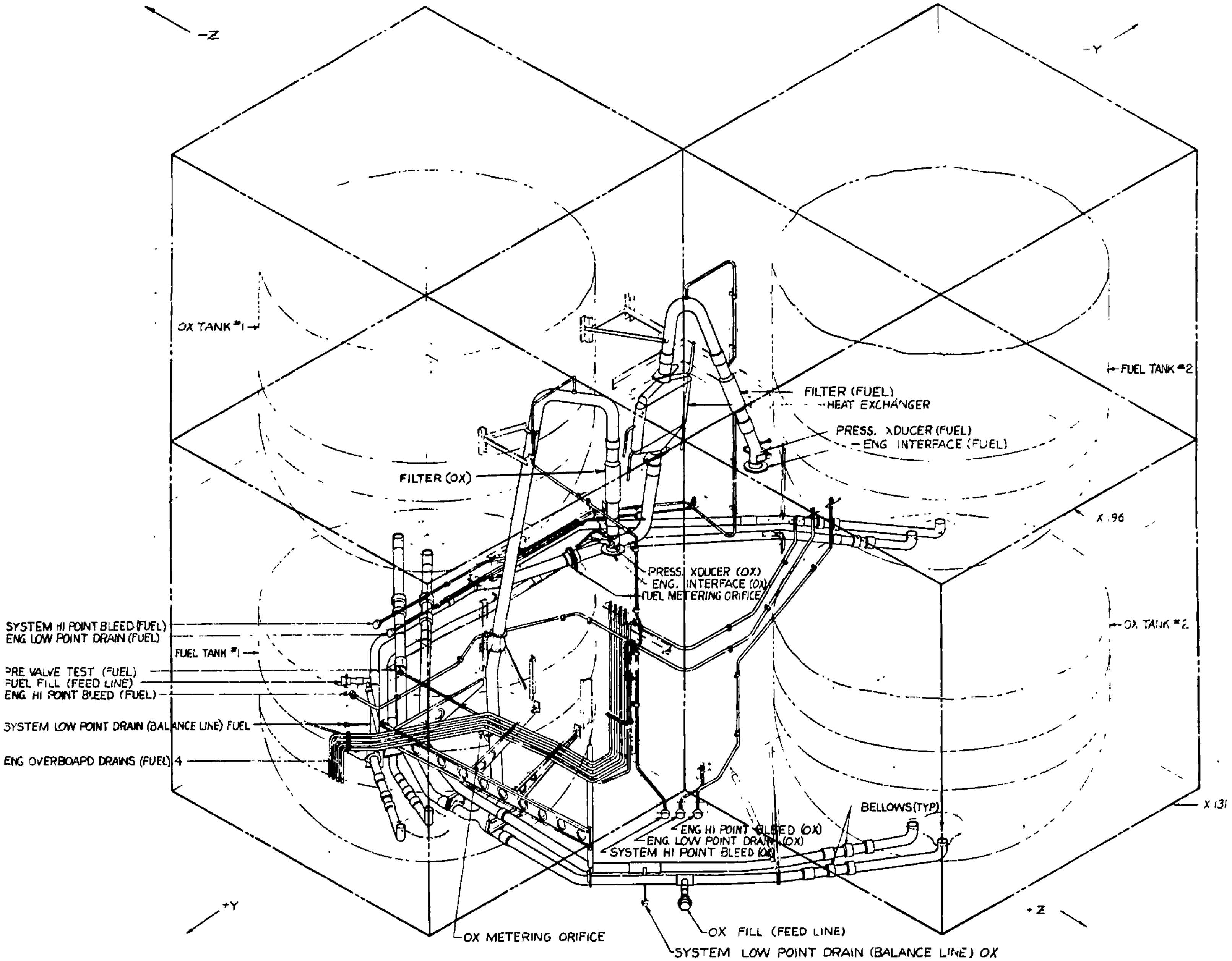


Figure 2.1-1 DPS Feed Section

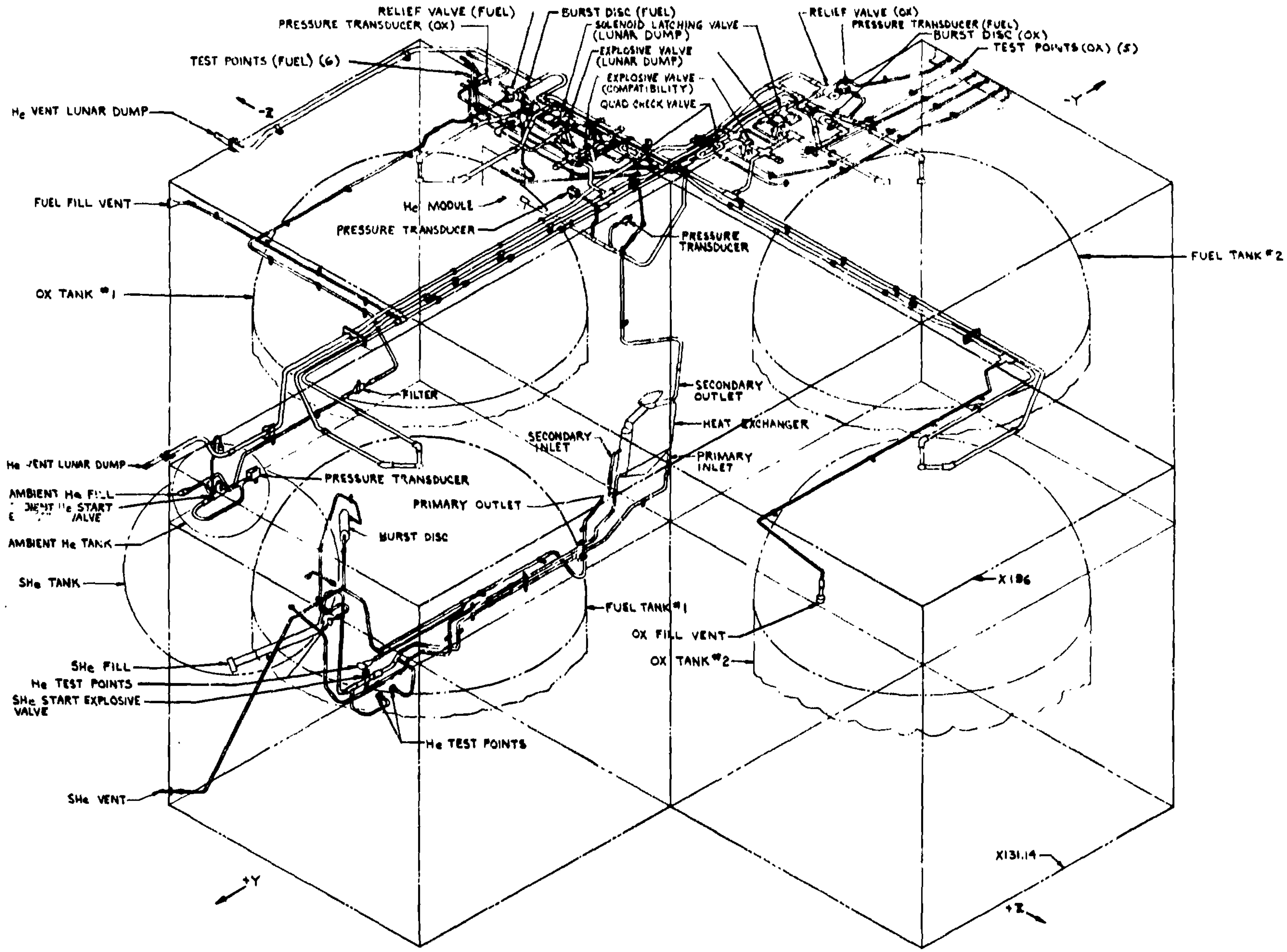


Figure 2.1-2 DPS Pressurization Section

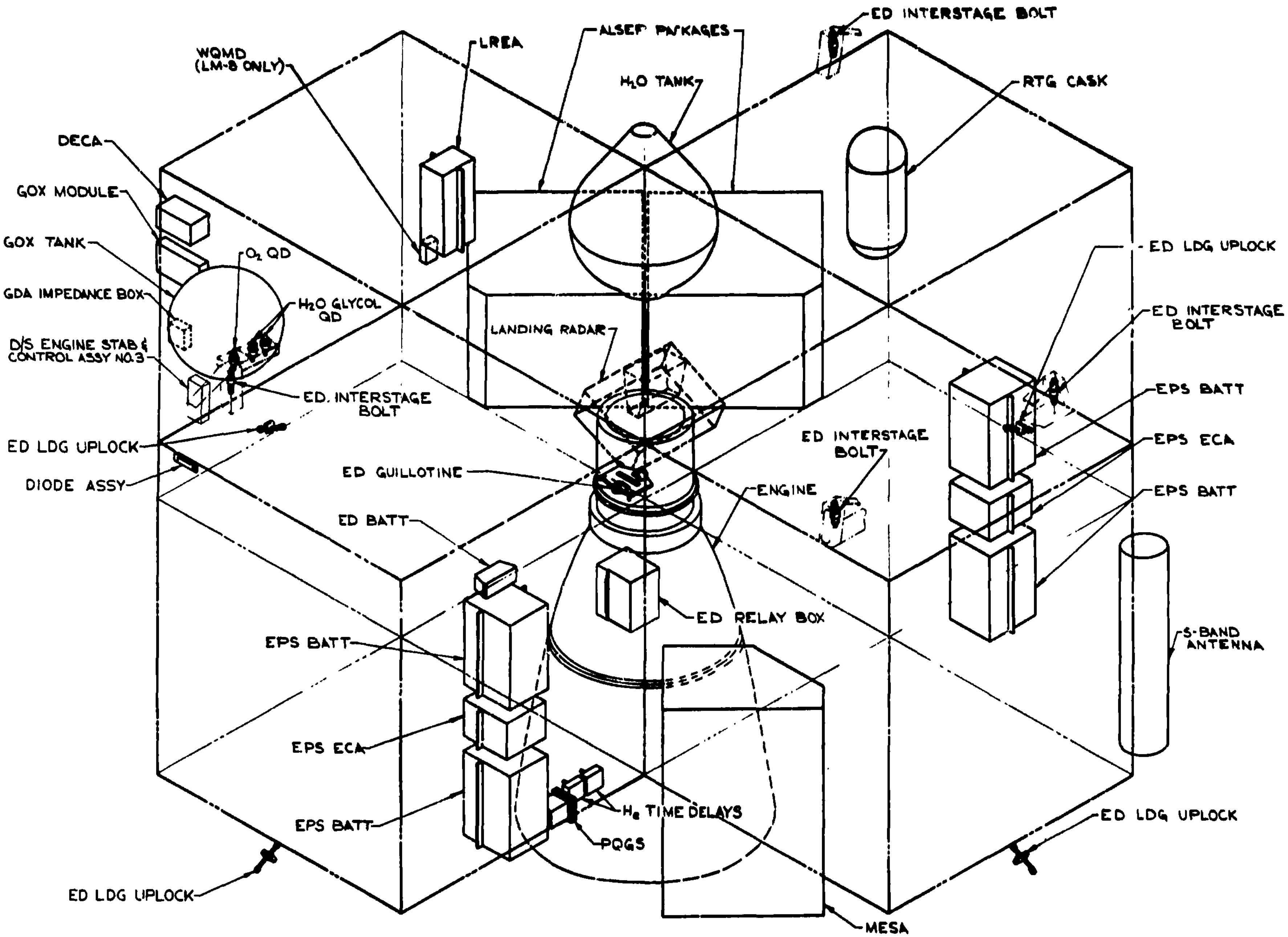


Figure 2.1-3 Descent Stage Equipment

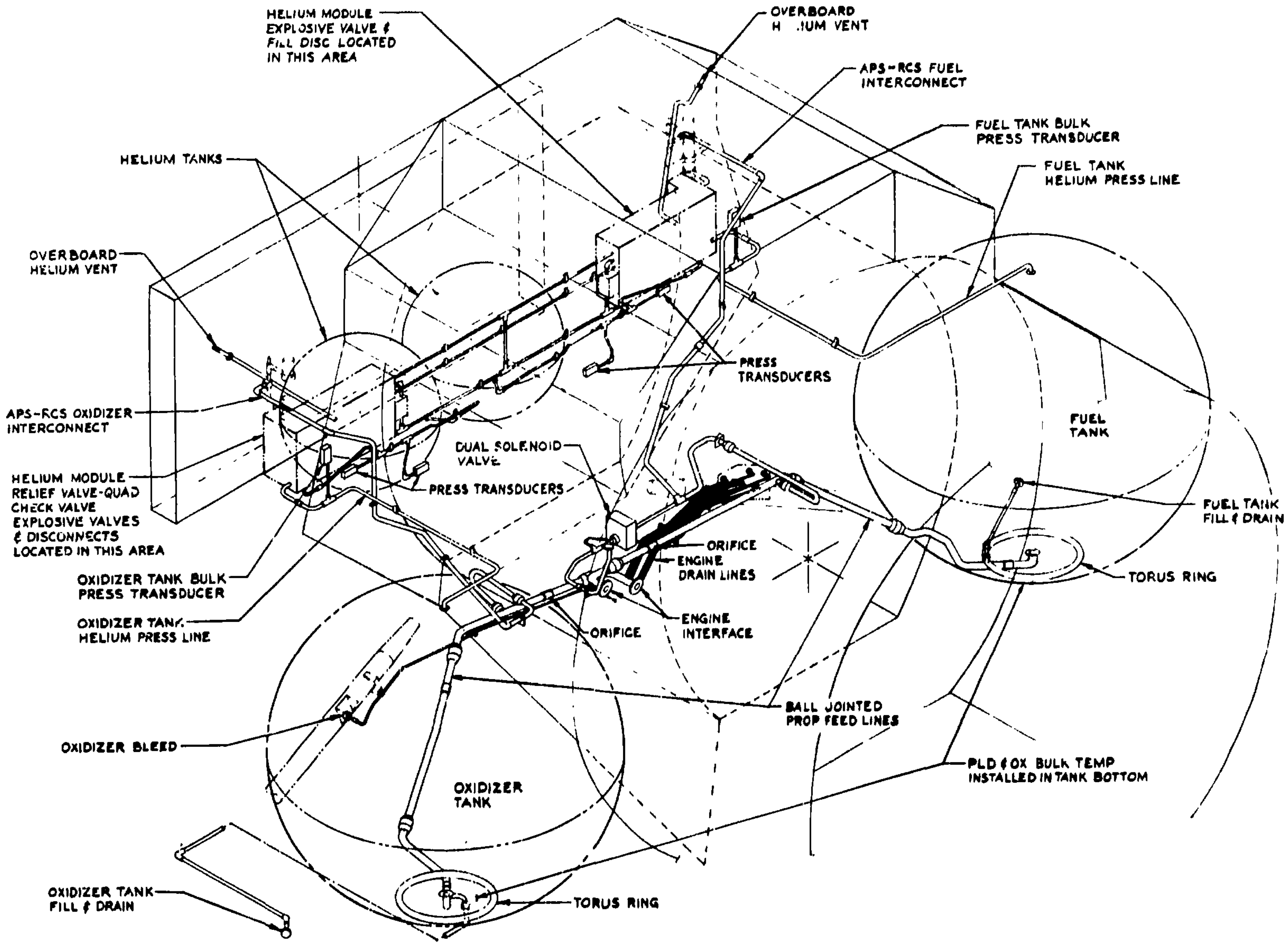


Figure 2.1-4 APS Feed and Pressurization Sections

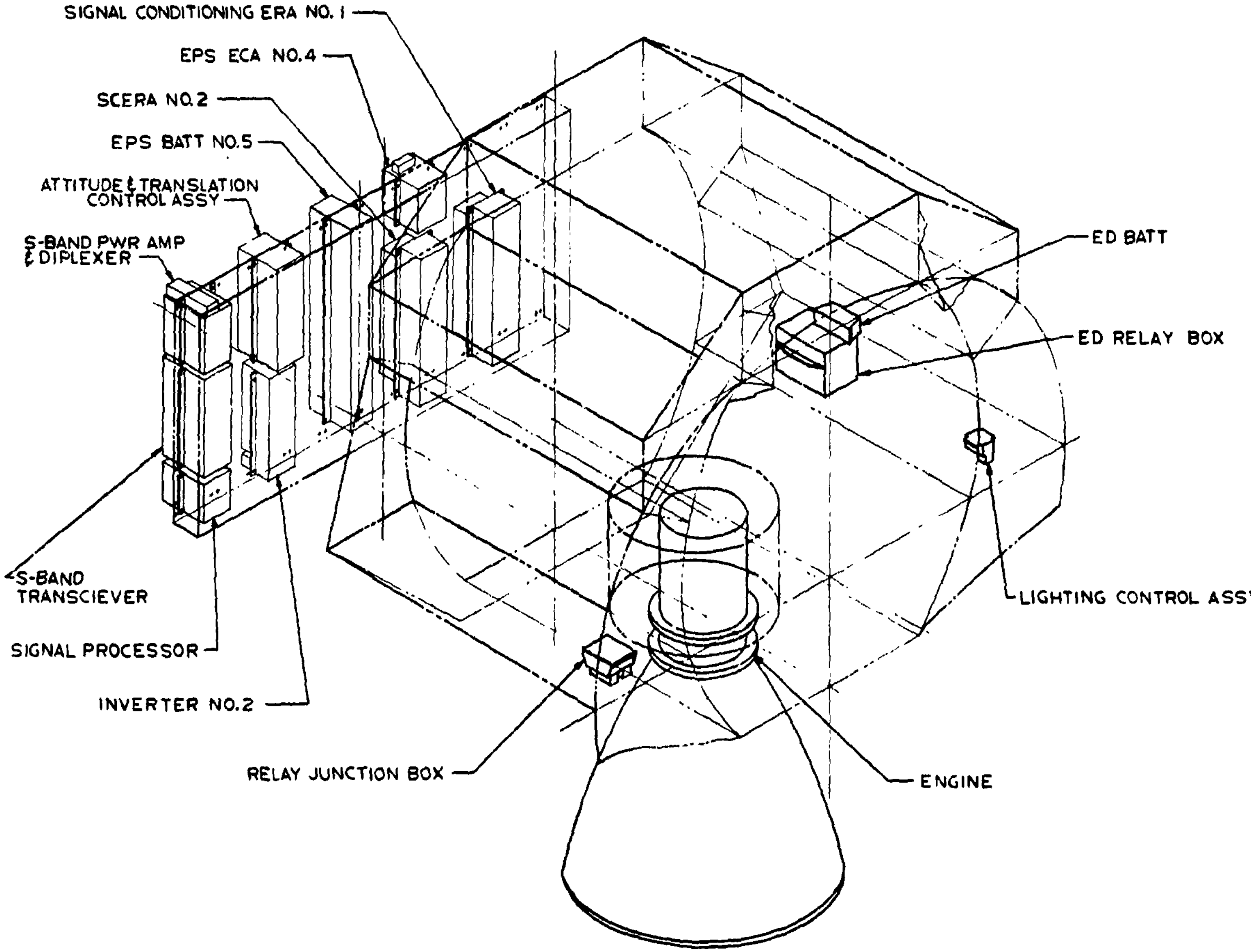


Figure 2.1-5 Ascent Stage Equipment

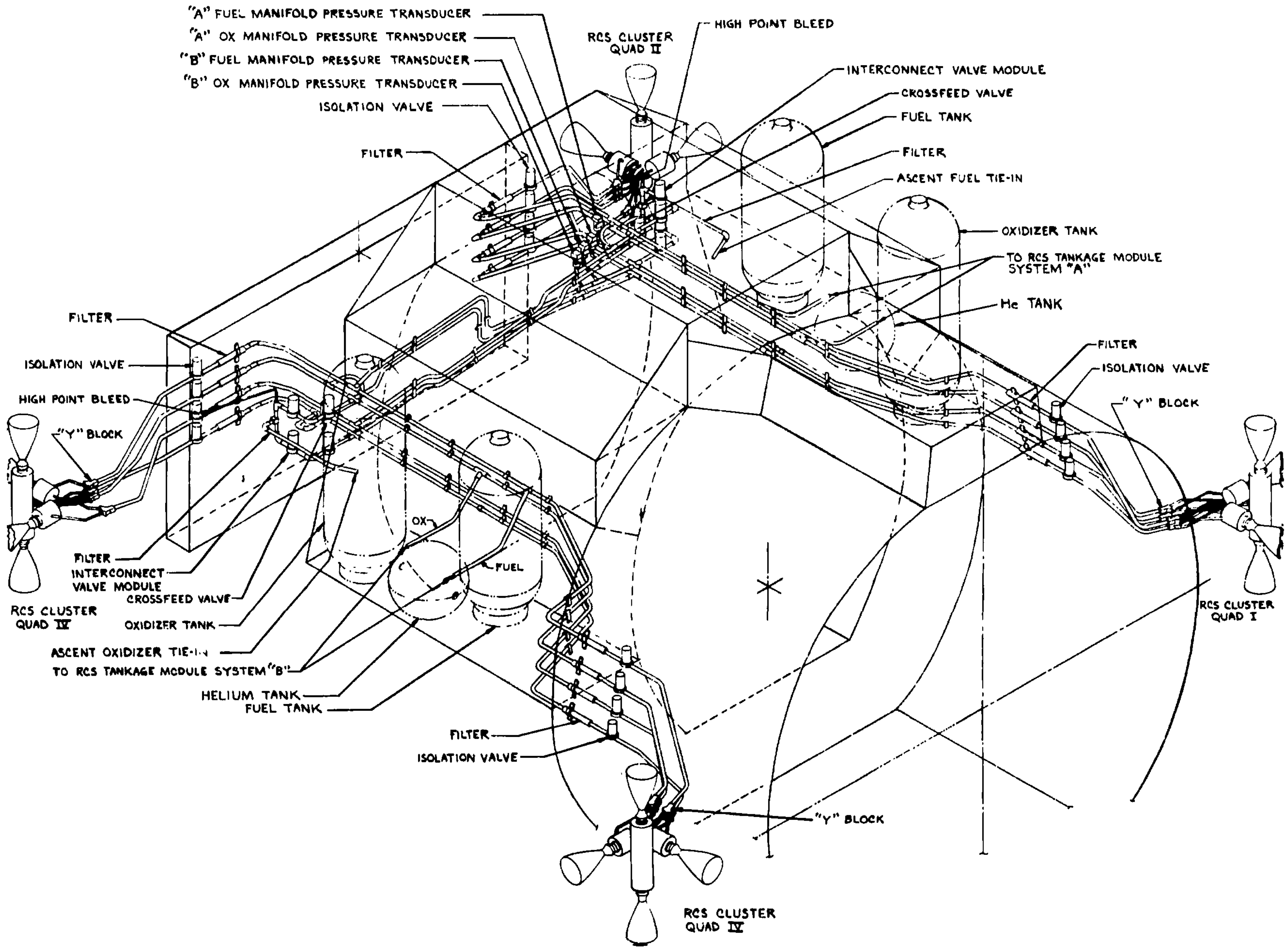


Figure 2.1-6 RCS

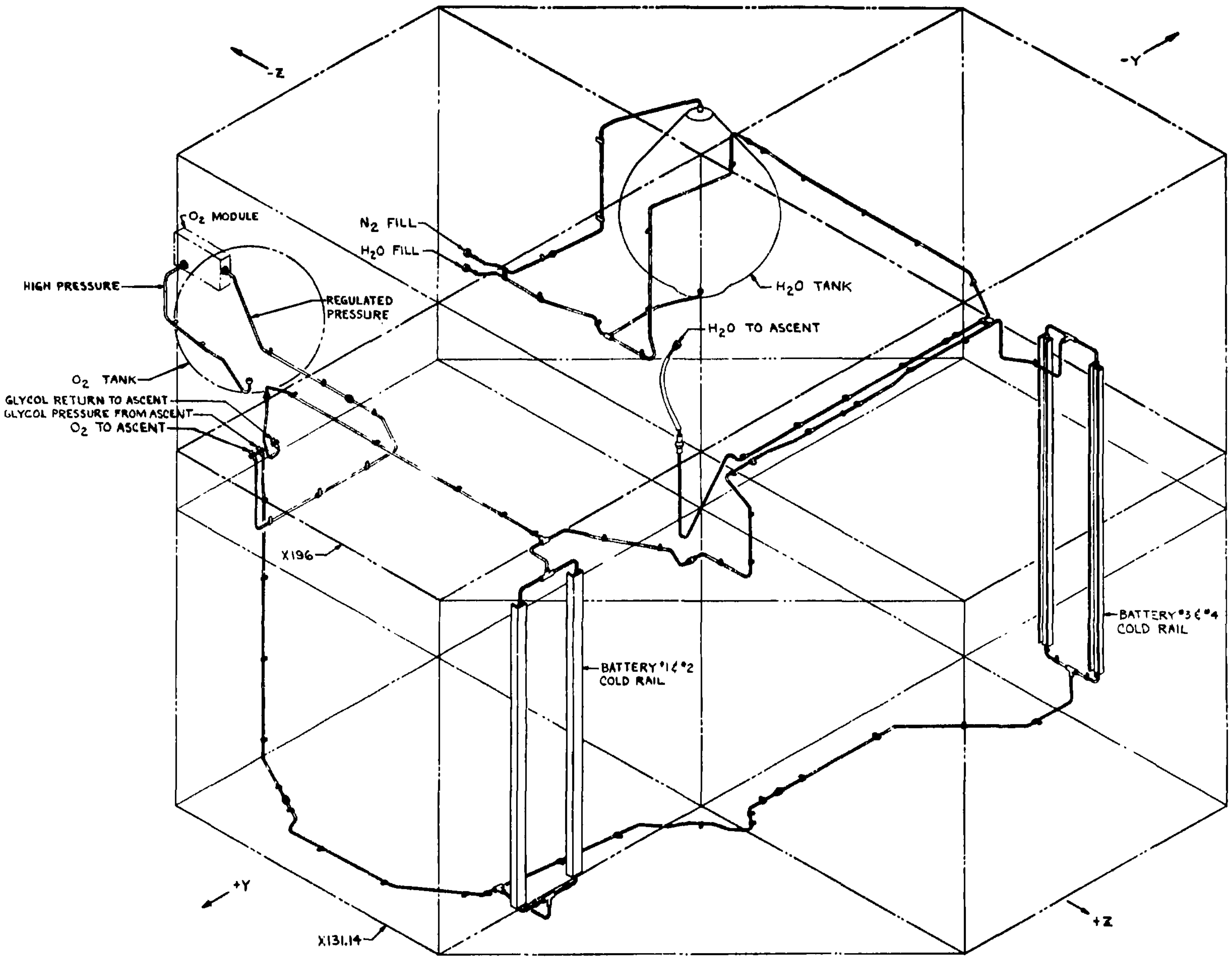


Figure 2.1-7 Descent Stage ECS Sections

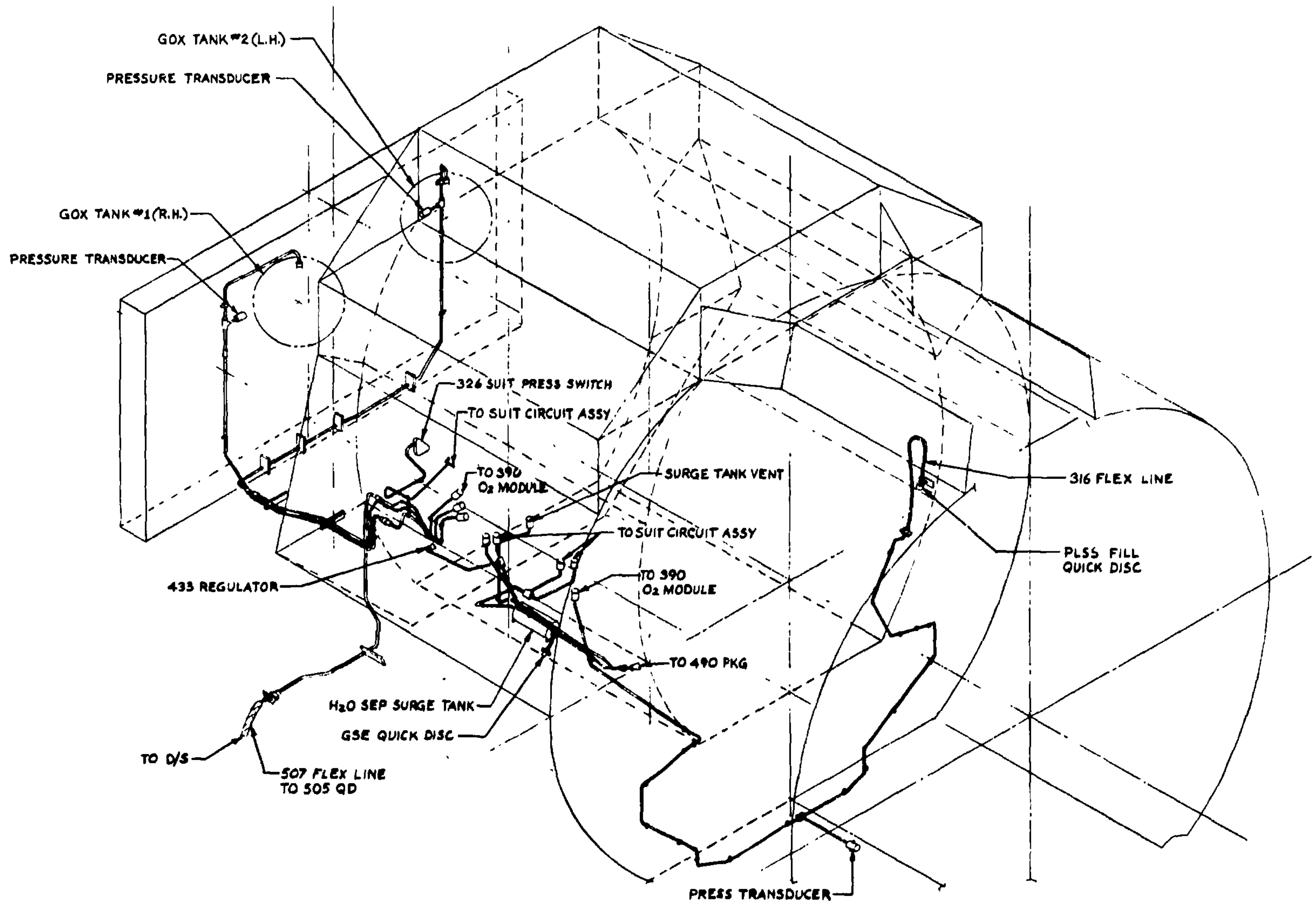


Figure 2.1-8 Ascent Stage ECS Oxygen Section

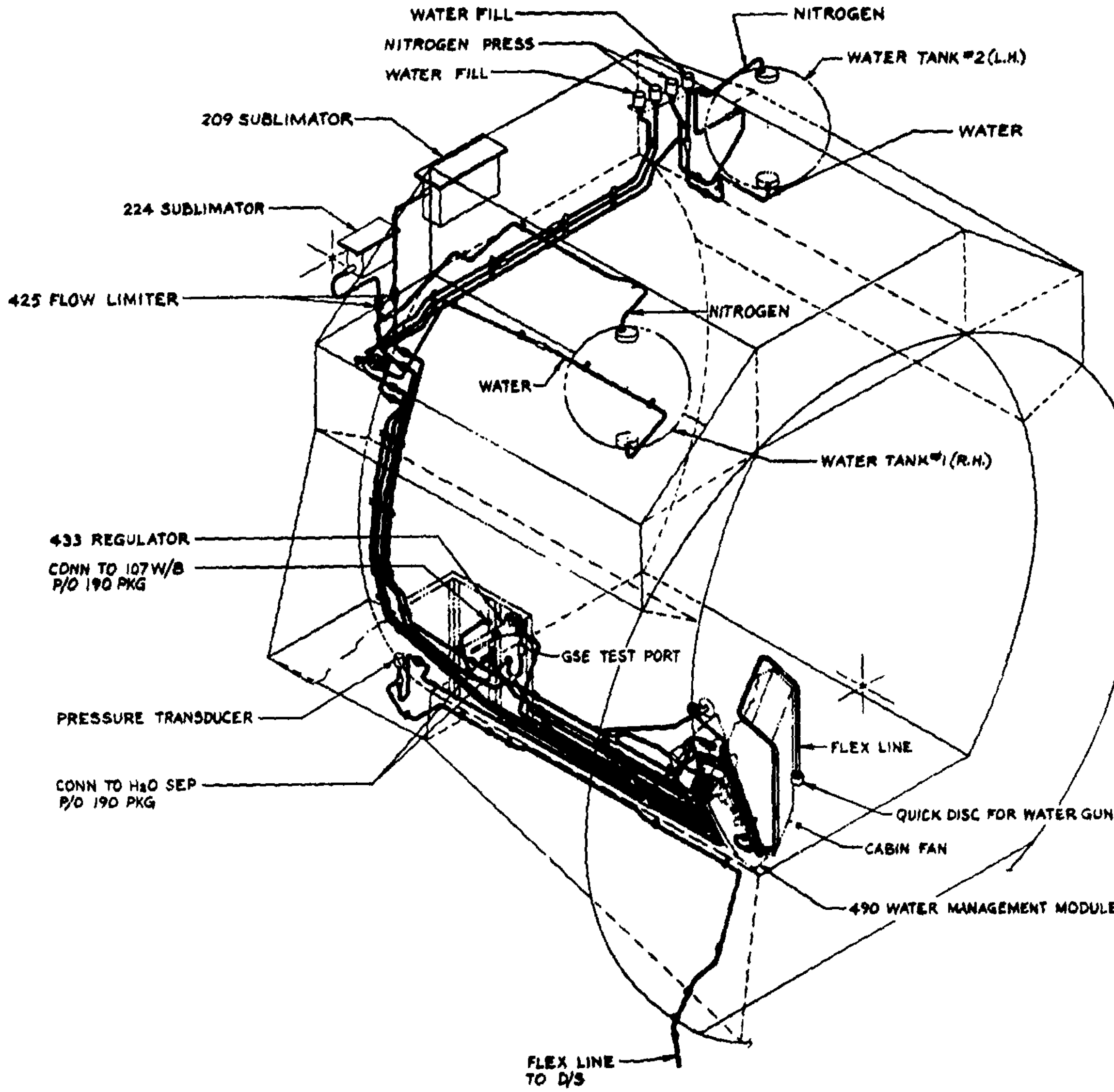


Figure 2.1-9 Ascent Stage ECS Water Section

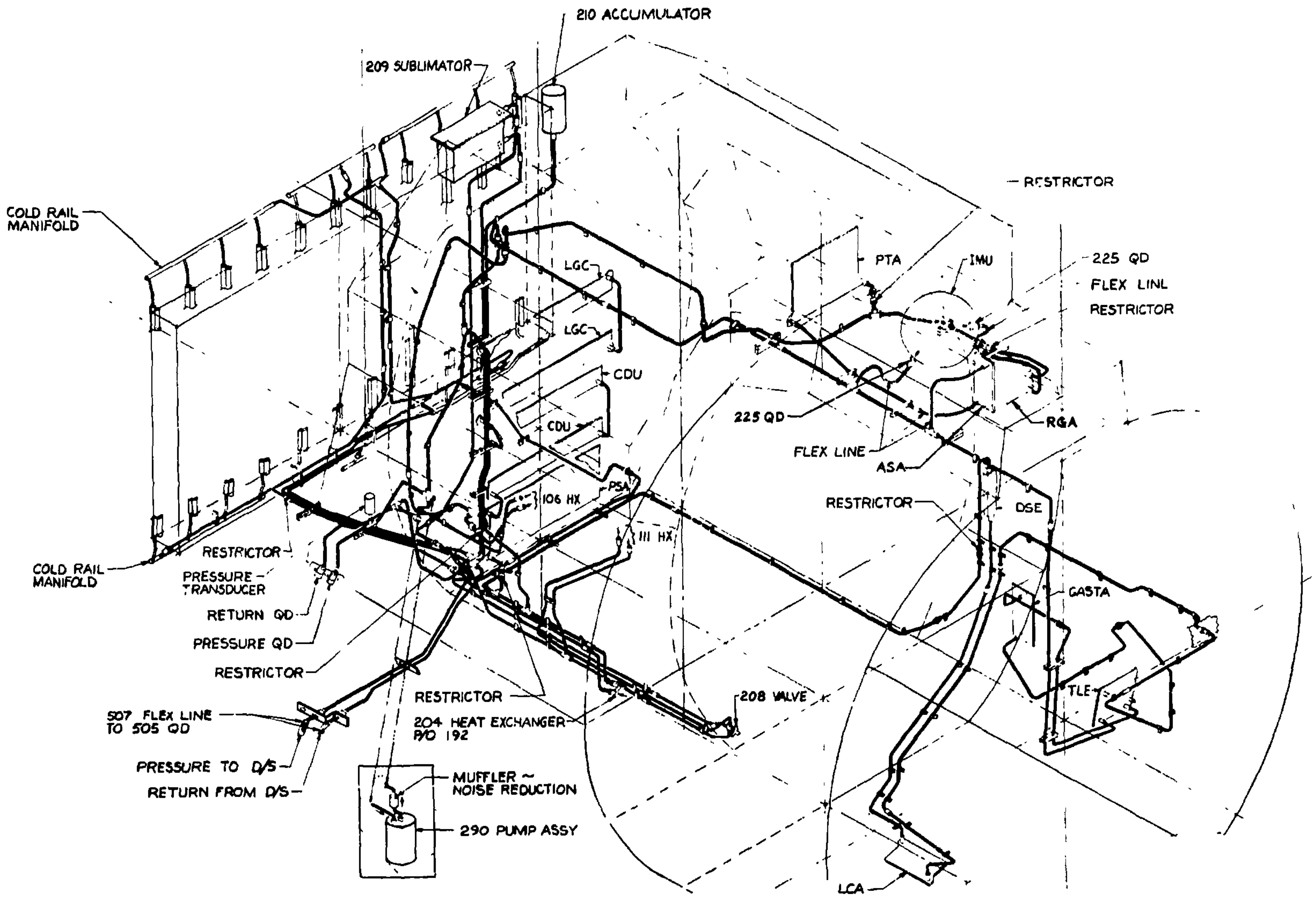


Figure 2.1-10 Ascent Stage Primary Coolant Loop

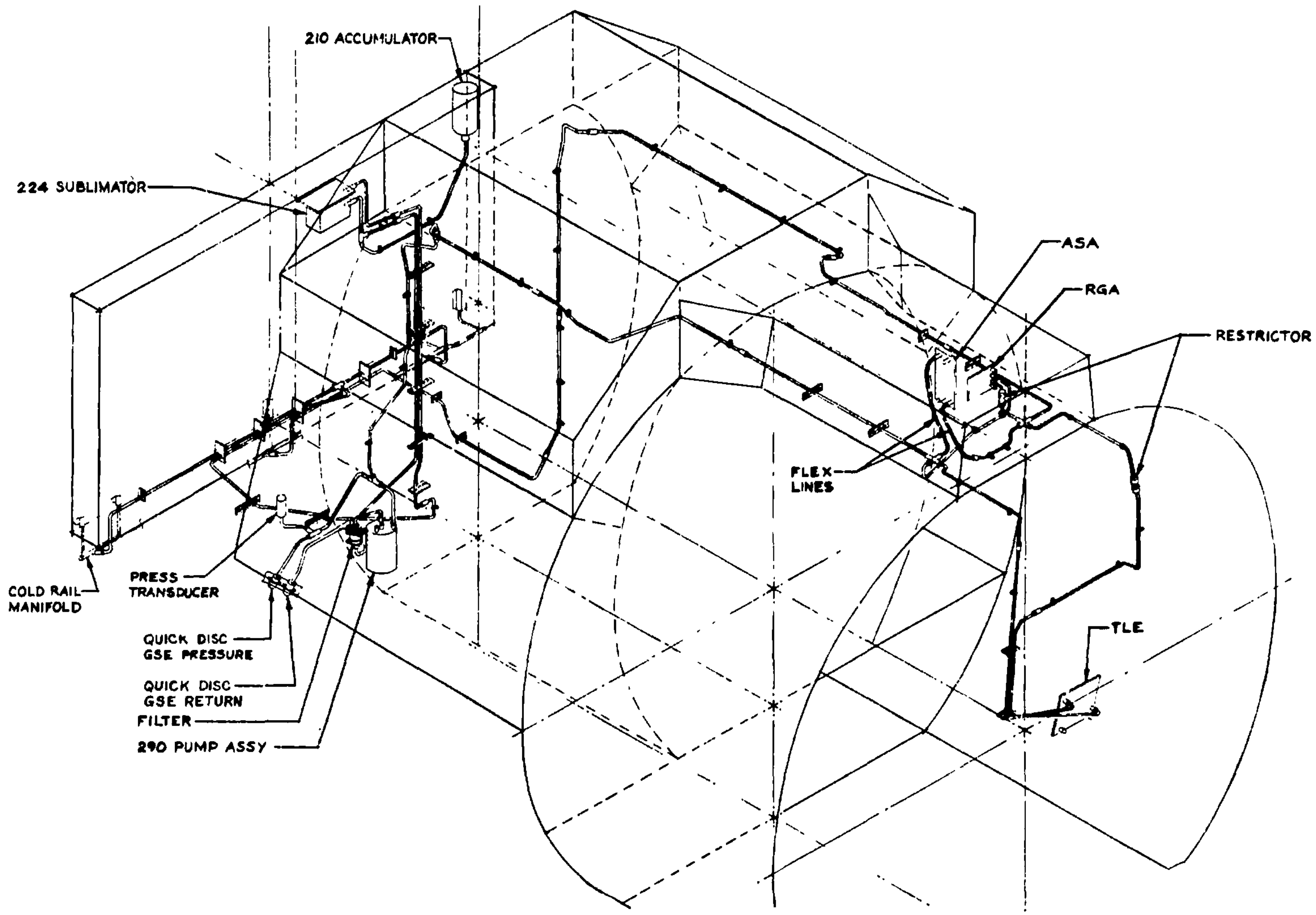


Figure 2.1-11 Ascent Stage Secondary Coolant Loop

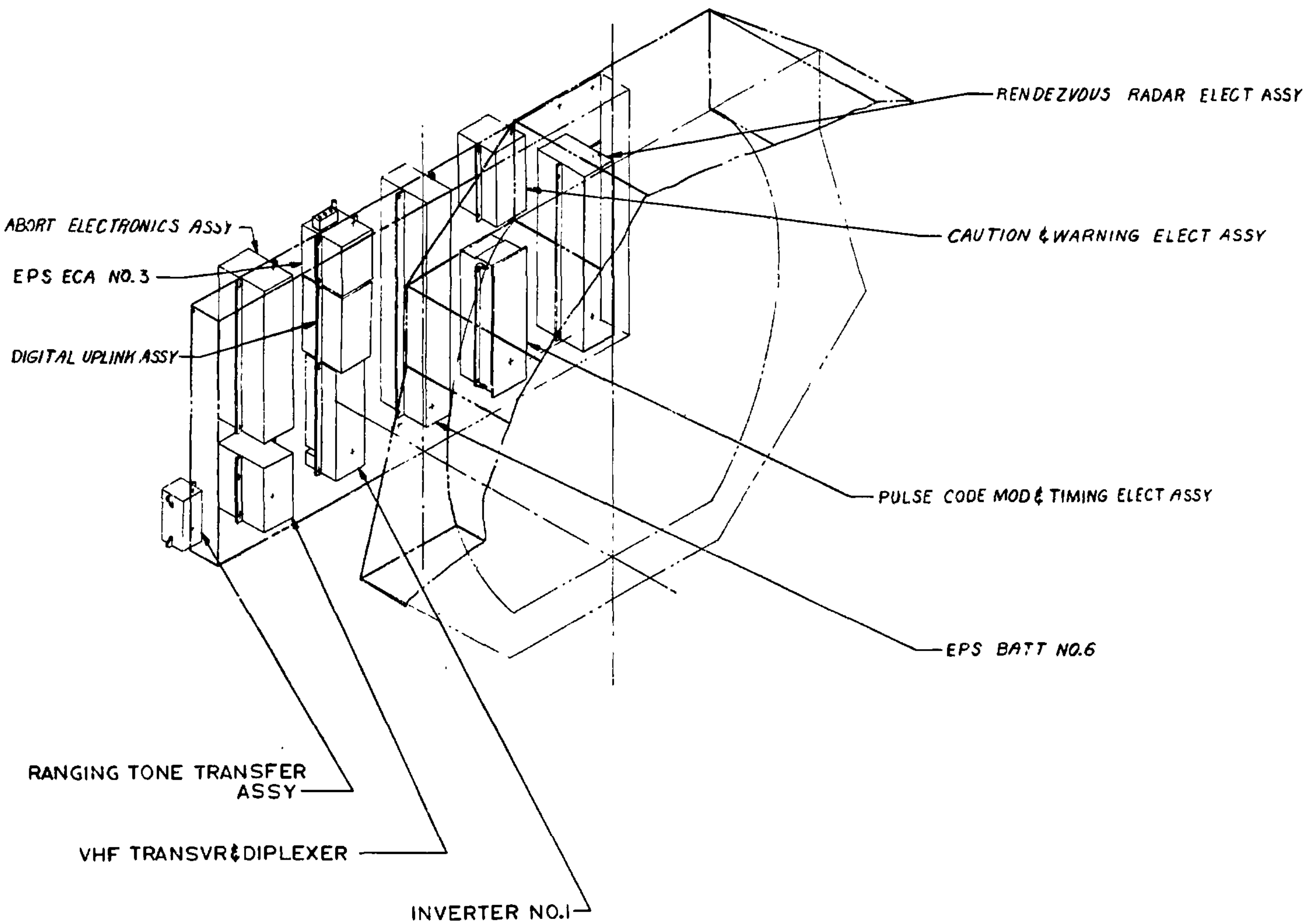


Figure 2.1-12 Ascent Stage Equipment

2.2 DESCENT PROPULSION SUBSYSTEM

The DPS, shown schematically in Figure 2.2-1, incorporates the ambient helium start tank, Figure 2.2-2; the supercritical helium (SHe) tank, Figure 2.2-3; and four propellant tanks, Figure 2.2-4. The two fuel tanks and two oxidizer tanks have similar internal and external configurations and are located in the ±Z bays (oxidizer) and ±Y bays (fuel) of the descent stage cruciform structure. The propellant tanks in the LM-10 and subsequent configuration were extended by increasing the length of the cylindrical section of the tanks. The balance lines were deleted and orifices were placed in the branch lines leading to the feed lines. The ambient and supercritical helium tanks are located in Quad III. Figure 2.2-5 is a photograph showing the supercritical and ambient helium tanks installed in the descent stage (bottom and upper right tanks).

For the purpose of identifying candidate components to investigate, it was assumed in this study that propellant and propellant vapors do not penetrate the system upstream of the reducing valve. The reducing valves are located downstream of the helium solenoid shut-off vales and upstream of the quad check valves. During pre-mission operations the vapors and propellants are isolated to that section of the system downstream of the compatibility squib valves. Actuation of the system requires that these valves be opened (fired) to permit helium flow from the helium tanks, through regulators and check valves, and into the propellant tanks. Helium pressure in these tanks causes propellant flow to the engine valves which are opened hydraulically after fuel is directed to the actuators by the pre-valve and the solenoid pilot valves. In the LM-7 configuration an orificed heat exchanger bypass line is included to prevent pressure build up in the fuel feed line, because of heat soakback after freezing fuel in the heat exchanger following lunar venting. In addition,

2.2 (cont'd)

the oxidizer fill vent was moved from Quad IV to the +Z 81 bulkhead for accessibility and three oxidizer disconnects (lower deck Quad IV), system high point bleed, engine high point bleed and engine low point drain were moved out to the heat shield beam in Quad IV for better accessibility.

The SHe tank is a vacuum-jacketed pressure vessel designed to a heat leak pressure rise rate not to exceed 10 psi per hour. In a nominal mission, tank pressure is reduced by venting on the lunar surface through the lunar dump system. Emergency venting of SHe tank over-pressure is through the dual burst disc assembly. Over-pressure ruptures both burst discs thereby venting the tank. It has been shown that the pressure rise effects of a "thermal short" of the SHe tank vacuum insulation are adequately handled by the burst disc assembly. No propellants or propellant vapors reach the tank assembly and all materials, metallic and non-metallic, are compatible with helium. Two pressure transducers are provided in a line from the SHe tank; the output from one is read out on a cabin meter, while the output from the other is transmitted through the PCM to the ground.

The ambient helium start tank is isolated from the pressurization system by a squib valve.

During pre-mission operations no venting means are provided after engine firing, the tank is vented through the regulators into the propellant tanks. In the LM-10 and subsequent configuration, as a result of the extended propellant tanks, the helium lines on the top deck were reconfigured and the ambient helium line on the -Z top deck was moved inboard to place it under the fiberglass heat shield. The ambient helium start tank pressure is monitored by a pressure transducer in the line downstream of the tank. The output signal goes to both a cabin display and to the PCM.

Each pair of propellant tanks is protected from over-pressure by a burst disc and relief valve assembly. The burst disc function is to protect the relief valves from the propellant vapors which have proven to be compatibility sensitive for long duration exposure periods. Burst disc rupture pressure is nominally 5 psi higher than the relief valve pressure, 275 psid maximum.

2.2 (cont'd)

Figure 2.2-4 shows the internal configuration of the propellant tank, and details of the tank bottom showing the relation of the bulk temperature probe and the propellant quantity gaging system to the non-electrical components within the tank. Other electrically operated components within the DPS downstream of the regulators, which could provide a propellent/electrical interface in a failure mode, are the ullage and interface pressure transducers, compatibility and lunar dump squibs, lunar dump and engine solenoid valves,and fuel pre-valve.

The transducers are essential parts of the flight instrumentation and are critical in the evaluation of the DPS operation during the lunar mission. Two pressure transducers (redundant) are included in the line just downstream of the regulators to monitor the regulator outlet pressure. The redundancy is required because of the importance of the regulated pressure with respect to the propellant tanks.

The ullage transducers are located in the helium lines upstream of the propellant tanks; the interface transducers are located downstream of the tanks in the feed lines near the engine interface. The squib valves isolate propellants and propellant vapors by parent-metal membranes until opened instantaneously by explosively severing the membranes. No electrical power is brought to the valves before or after operation, but only during the instant of detonation of the explosive charges.

The lunar dump solenoid valves are used to control the duration of venting after the lunar dump squib valves are opened. They are isolated from propellants and propellant vapors until the lunar dump mode is activated by the squib valves. They are flown latched open and are not activated closed until pressure in the propellant tanks has been greatly reduced. The lunar dump squib valves and solenoid valves are located upstream of the propellant tanks parallel to the relief valves and burst discs in both the oxidizer and fuel sections. In the LM-10 and subsequent configuration the lunar dump helium vent ports were relocated to allow for structural changes to incorporate the extended propellant tanks.

2.2 (cont'd)

In the DPS, the pre-valves are part of the descent engine assembly and are located downstream of the engine interface. When opened they expose the engine solenoid pilot valves, located further downstream, to pressurized fuel. Opening of the solenoid pilot valves exposes the ball valve actuators to the pressurized fuel.

The following paragraphs describe conditions where fewer than three mechanical failures could cause pressure vessel rupture.

Mixing of hypergolics could cause an overpressure condition in the oxidizer tank or, in a worst case, an explosion. This condition can be caused by only one failure, internal leakage of the fuel/SHe heat exchanger. Fuel could leak into the helium system via the external heat exchanger, depending on the relative pressures of the fuel and helium sections downstream of the SHe squib valves prior to the descent engine firing. Fuel could be introduced into the common helium manifold which feeds the oxidizer tanks and cause the overpressure condition.

A failure of this type occurred during DVT testing in 1966 (FSW06). There was a crack at the weld joint between the fuel collector and the side panel during vibration. The failure was caused by lack of adequate internal support at the mounting location, stress concentration and flexure of side panels. This problem was resolved by increasing the panel thickness, adding external stiffeners and redesigning the weld.

A double failure of a quad check valve can be postulated in the DPS or APS which could lead to hypergolic propellant mixing. It requires two poppets in series in either valve to fail open and thereby provide a flow path for either propellant. In addition, the potential for liquid flow must be established via either a temperature or pressure gradient and liquid must be simultaneously positioned at the helium diffuser to be forced into the helium lines. Given these conditions in sufficient quantity and an additional condition of a relatively small ullage volume, it is possible to theorize a situation whereby a volume of one propellant could be swept into the opposite propellant tanks during a subsequent period of pressurant flow, which could result in a catastrophic pressure spike in the tank where the mixing took place.

2.2 (cont'd)

if the propellant being transferred in the above example were in the vapor phase rather than liquid, the reaction in the opposite tank would be much less violent. In the worst case it is expected that the relief system of the propellant tank would be capable of relieving any pressure spike from a propellant vapor transfer.

There have been numerous leakage failures (ranging from just-out-of-specification to full-open conditions) on the quad check valves. The test specification for leak checking quad check valves at GAC is 100 sec/hr max allowable leakage per element and valve assembly with 8 to 10 psid reverse pressure applied. The specification is the same for KSC testing except for a recent change which allows single element leakage of 300 scc/hr as long as the element in series is 100 scc/hr maximum, i.e., the valve assembly shall not exceed 100 scc/hr. Each occurrence is presently evaluated to determine whether the unit is rejected or the condition is waived. The propellant tanks can also rupture as a result of the following two failure combinations. The first combination of failures involves a high pressure helium leak, after descent engine firing, from the supercritical He section into the fuel section via the fuel/SHe heat exchanger and the fuel tank relief valve to fail closed. The failure history on the fuel/SHe heat exchanger was discussed above. Two experiences of the propellant tank relief valve failing closed have been noted:

(a) During qualification testing of the relief valve, the crack and reseat pressure band shifted due to a gummy substance found in the housing bore which could cause the valve to stick closed (ref. FR#FMCR48). This substance is believed to be a product of the reaction between fuel and CO_2 in the atmosphere. These test conditions were considered to be unrealistic and test procedures were altered to run tests (liquid fuel) under vacuum conditions.

(b) The inability of the relief valve to meet the required flow rate of 4 lb/min at 255 psid occurred during qualification testing at the vendor (FMCR51). The cause and rationale for corrective action are the same as noted in (a) above.

2.2 (cont'd)

The second overpressure condition occurs if the primary Helium regulator fails open and either of the propellant tank relief valves or bust discs fail closed. This is based on the assumptions that the descent propulsion subsystem has been pressurized and, furthermore, that the crew reaction time to implement corrective action exceeds 6 seconds. Note, both oxidizer and fuel relief valves and burst discs must operate in order to dump the full flow of a failed-open regulator. The regulator is orificed for a failed-open flow of 19 lb/min and each relief valve is capable of dumping only 10 lb/min. During acceptance testing of the ascent regulators at Fairchild, a helium regulator (P/N LSC 270-721-7-4) froze open. This icing condition (ref. FFC 2748) was a result of inadequate protection from atmospheric conditions. This problem was resolved by adding heat sealed polyethylene bags to protect the regulator. Failure history for the propellant tank relief valves was provided above.

A similar overpressure condition of the propellant tanks can occur when pressurizing the system with the ambient helium start tank, if the secondary Helium regulator fails open and the propellant tank relief valve or burst disc fails closed. For this failure, the possibility of the crew isolating the failed regulator does not exist, since the start tank is downstream of the solenoid shut off valve. In this case the crew could try to relieve pressure through the lunar dump system. However, if a slug of liquid propellant flows through the lunar dump (Parker) solenoid valve, the flow dynamics may cause the valve to close. The only other recourse would be to stage the vehicle.

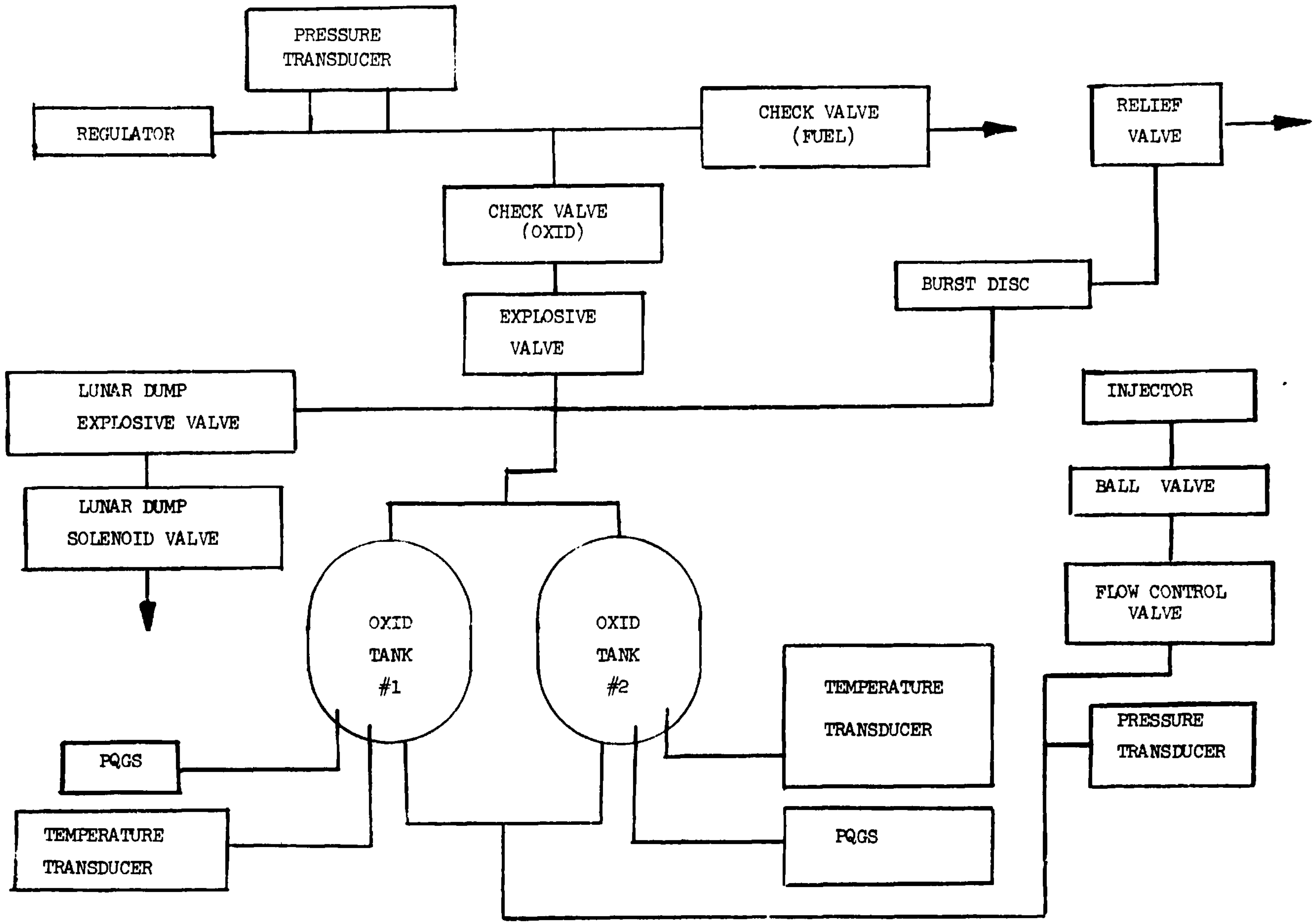


Figure 2.2-1A DPS Oxidizer System

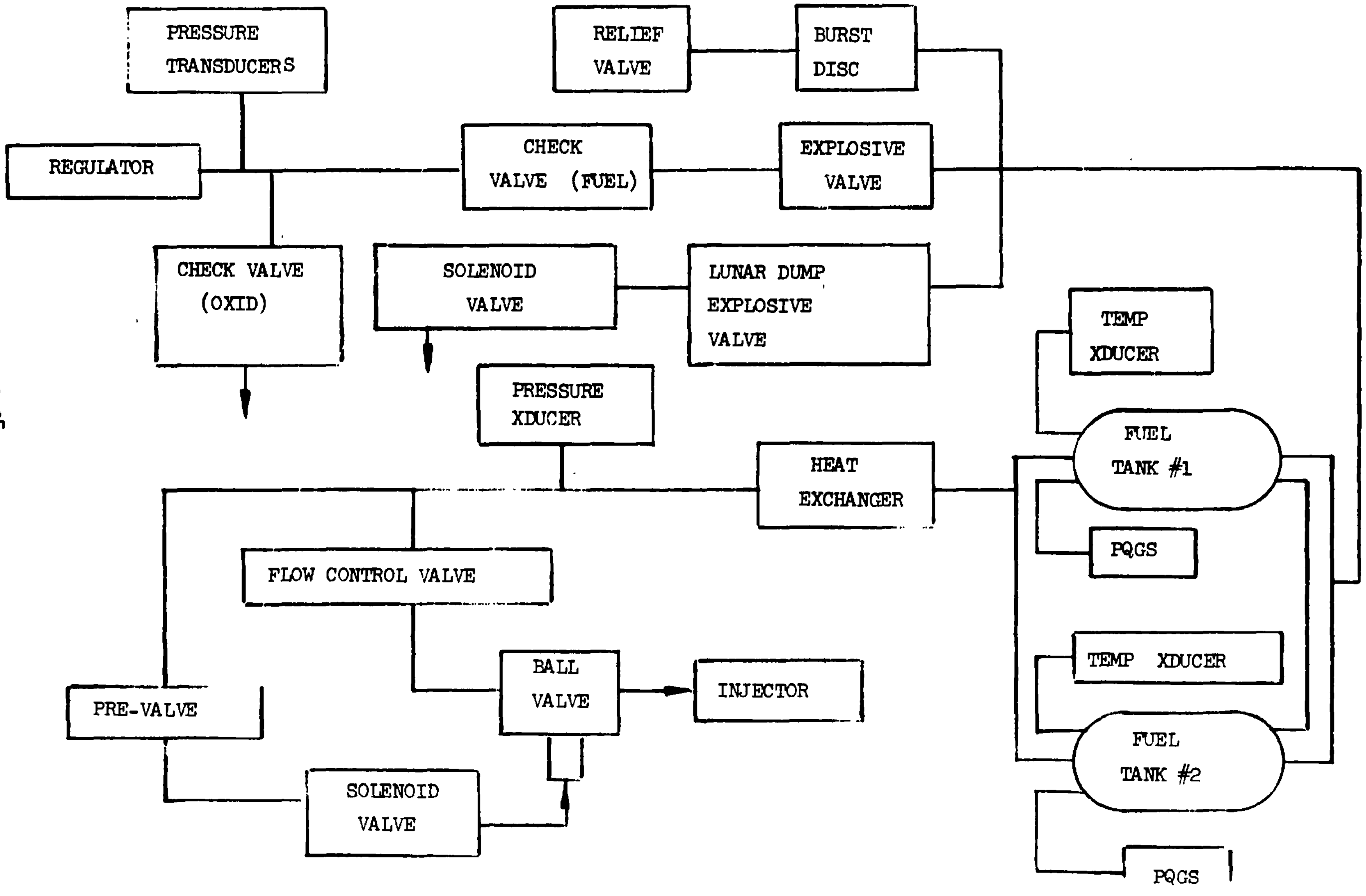


Figure 2.2-1B DPS Fuel System

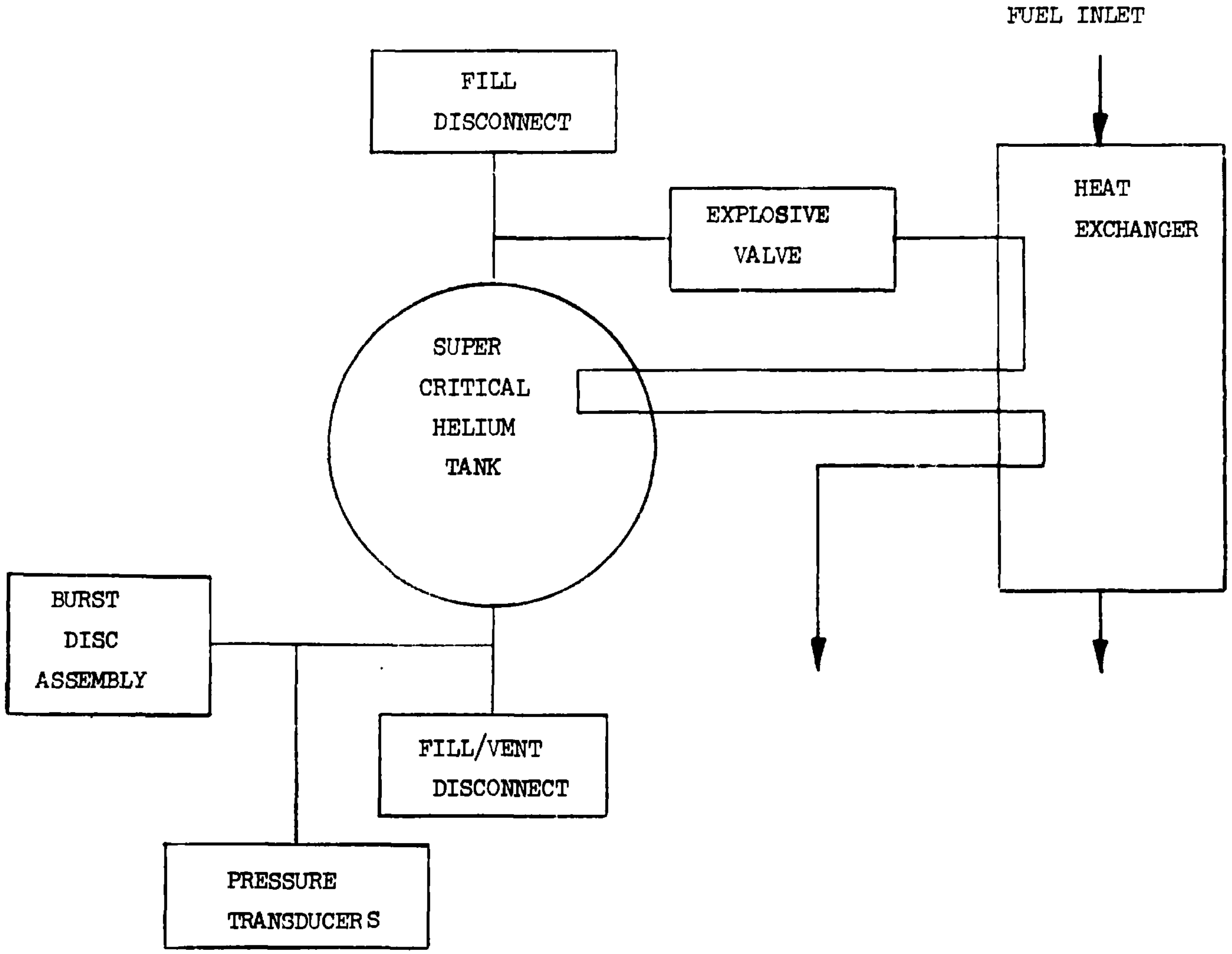


Figure 2.2-1C DPS SHe System

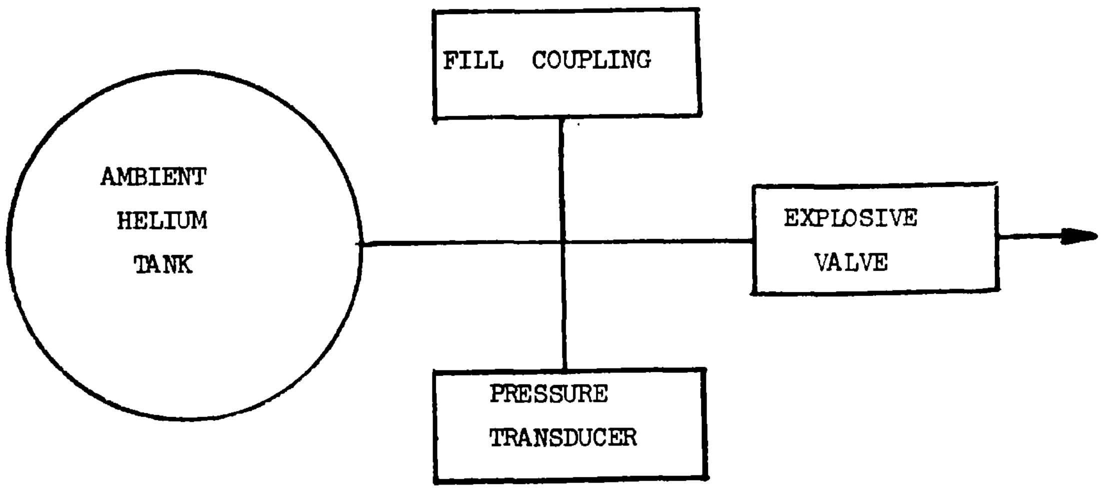


Figure 2.2-1D DPS Ambient Helium System

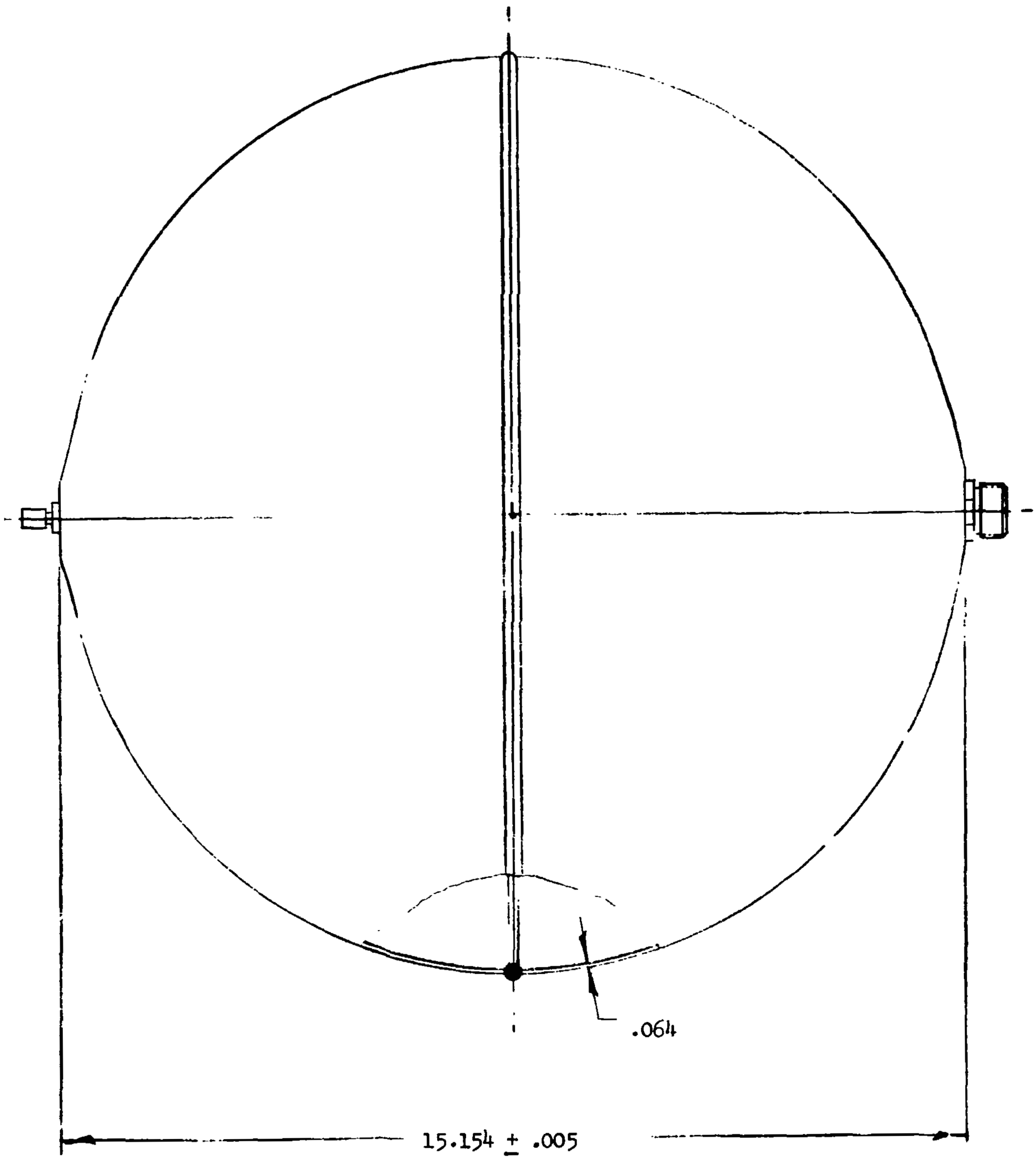


Figure 2.2-2 DPS Ambient Helium Storage Tank

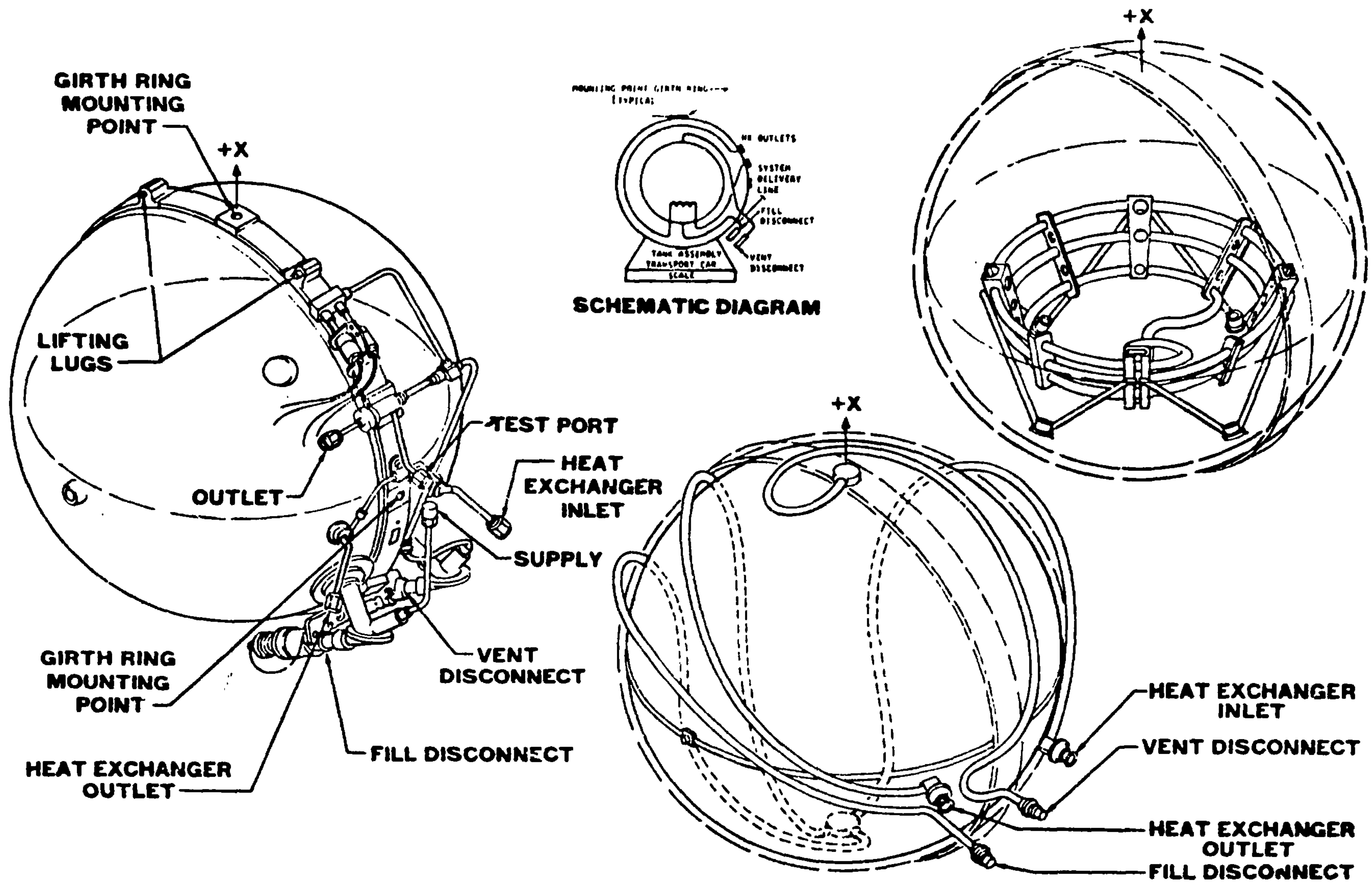


Figure 2.2-3 DPS SHe Tank

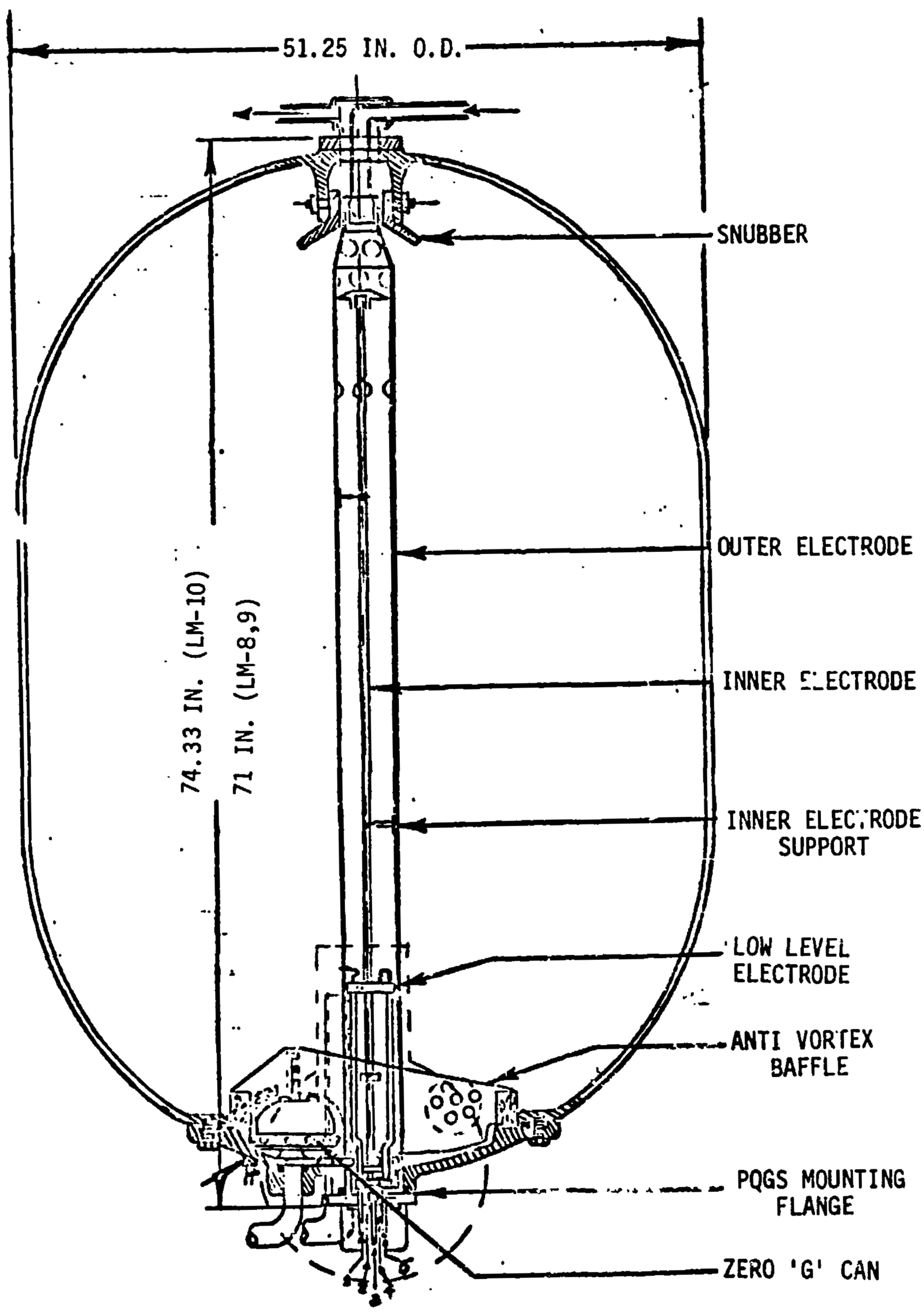


FIGURE 2.2.4. DPS PROPELLANT TANK

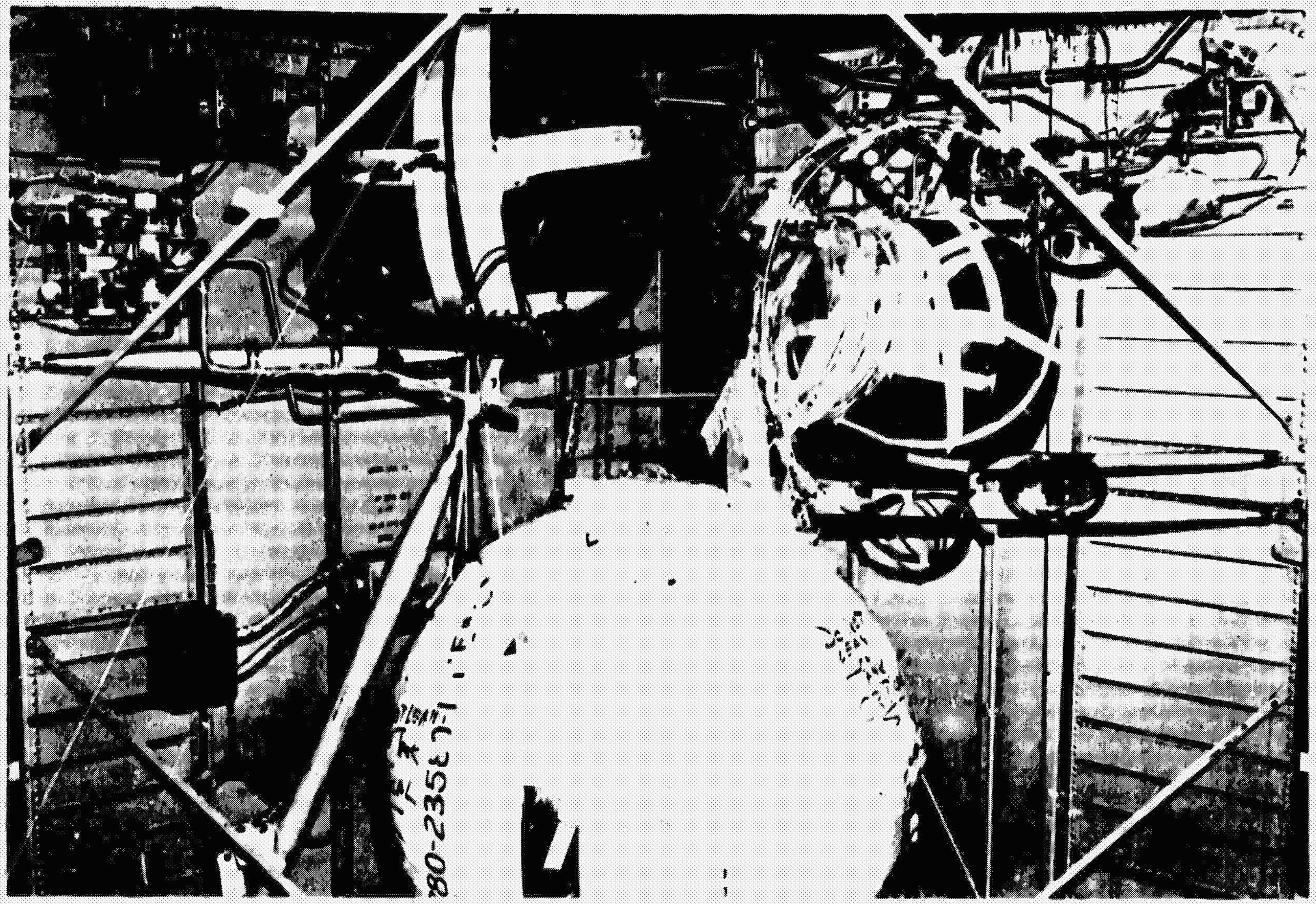


Figure 2.2-5 D/S Quad III: GOX, DPS Amb. He & SHe Tank

2.3 ASCENT PROPULSION SUBSYSTEM

The APS is shown schematically in Figure 2.3-1. Two ambient helium storage tanks, Figure 2.3-2, and two propellant tanks, Figure 2.3-3, comprise the pressure vessels in the system. The ambient helium storage tanks are located in the aft equipment bay. The propellant tanks are supported externally on the ascent stage along the $\pm$Y axis. Figure 2.3-4 shows a detail view of the propellant tank bottom. Figure 2.3-5 is a photograph showing an installed fuel tank (lower tank) and Figure 2.3-6 shows the helium tank installation (two larger tanks).

With the exception of the lunar dump valve in the DPS and the RCS-interconnect valve in the APS, the functional operation of the APS downstream of the regulators is similar to that of the DPS.

Both the oxidizer and fuel tanks are identical with respect to functional operation. Each tank system includes line components from the quad check valves to the engine interface flange. High pressure helium from the storage tanks is reduced to 184 psig (nominal) and fed to the oxidizer and fuel quad check valves. The helium reducer valves (regulators) are located downstream of the solenoid shutoff valves and upstream of the quad check valves. Two pressure transducers (redundant) are included in the line downstream of the regulators to monitor regulator outlet pressure. The propellant and pressurization sections are isolated by explosive valves, located downstream of the check valves, until the system is operated. The tanks are protected from overpressurization by relief valves with integral burst disc assemblies set to relieve at 250 psig (max). The relief valve assemblies are located off of the helium lines upstream of the propellant tanks. In addition, the propellant lines contain test point disconnects utilized for check valve and relief valve testing, disconnects utilized for tank filling and disconnects for venting during the fill process. No propellant tank or feed line changes were made in the LM-10 and subsequent configuration. Pressure transducers are included in the feed line downstream of the propellant tanks near the engine interface to monitor the inlet pressure to the engine valves. These transducers could be used to indicate propellant tank pressures during static conditions. The fuel-tank system contains a pre-valve assembly. This is a solenoid operated device which when opened provides pressurized fuel through the solenoid pilot valves to the engine ball valve drive actuators permitting engine operation. A pressure

2.3 cont'd

transducer is attached to the ascent engine chamber to monitor chamber pressure during engine burns.

The APS helium tanks contain the supply gas for propellant tank pressurization. Each tank system consists of a single-ported titanium tank with line components consisting of a fill disconnect, temperature transducer and pressure transducer. The temperature and pressure transducers are located in the line downstream of the tank. The tank is isolated from the downstream pressurization components by an explosively actuated (squib) valve. No automatic over-pressurization relief capability exists in this system since helium is loaded at ambient temperature and the aft equipment bay, where the tanks are located, provides an ambient environment. Two helium tanks are utilized to provide partial APS redundancy; the supply of one tank is sufficient to expel the propellant from the APS tanks for a normal LM ascent from the lunar surface. In the LM-10 and subsequent configuration the temperature transducer is deleted and a redundant pressure transducer is installed in its position in both helium tank lines.

The oxidizer and fuel pressurization lines incorporate pressure transducers mounted approximately 6 ft from the tank inlet. Both propellant tanks have temperature transducers and propellant level indicators whose sensing elements are internal to the tank and mechanically mounted to the tank bottom.

Presently, the APS propellant low level detector is used to provide a warning of imminent propellant depletion to the crew (approximately 8-10 seconds burn time remaining) as a cue to terminate ascent feed through the APS-RCS interconnects. This is the only requirement for the PLD and if this cue were supplied via another method, such as time or ΔV remaining, the PLD could be eliminated. This is currently being considered because the present 10 seconds is not adequate to evaluate interconnect status and to permit alternate or corrective action prior to APS depletion in the event of a malfunction.

An APS propellant tank rupture is possible as a result of loss of pressure in the tank during high-g mission phases (i.e. - launch-and-boost and lunar landing). A pressure decrease below 62 psi would exceed the demonstrated capability of the tanks.

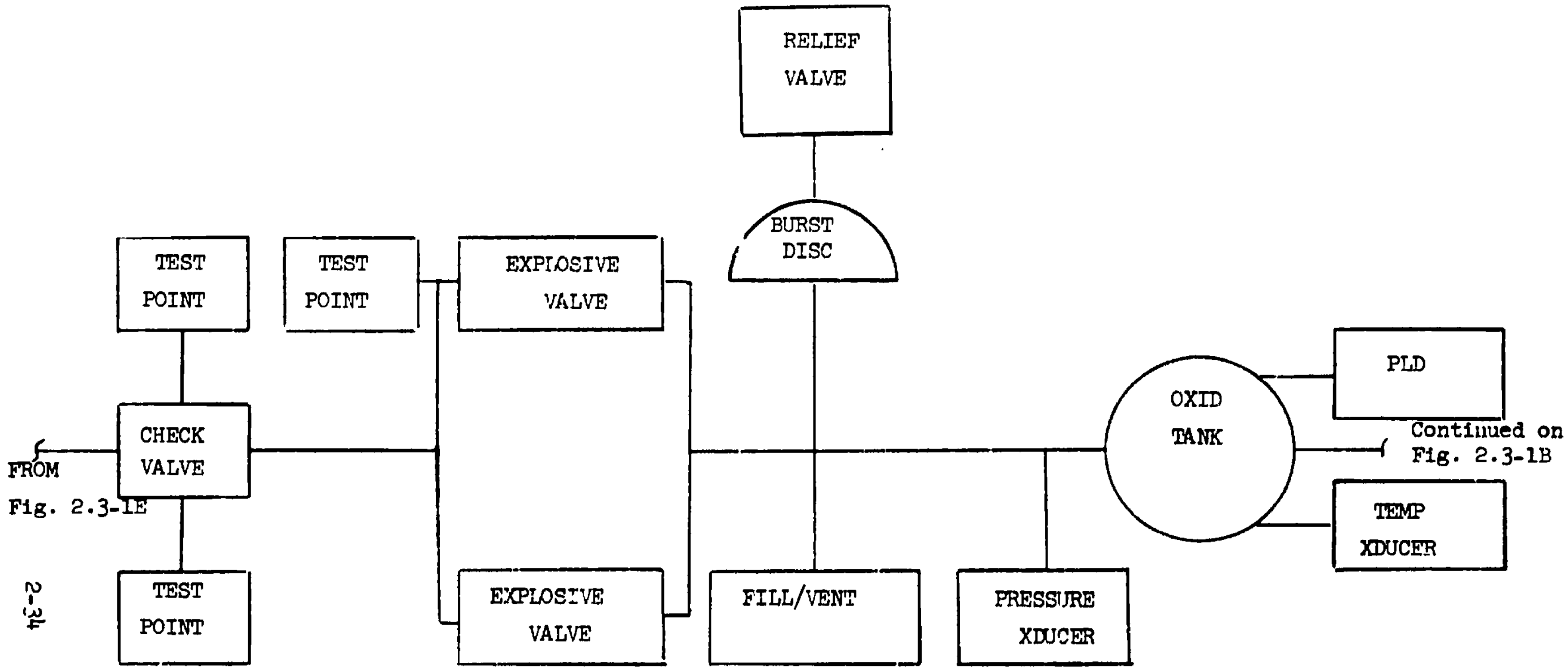


Figure 2.3-1A APS Oxidizer System

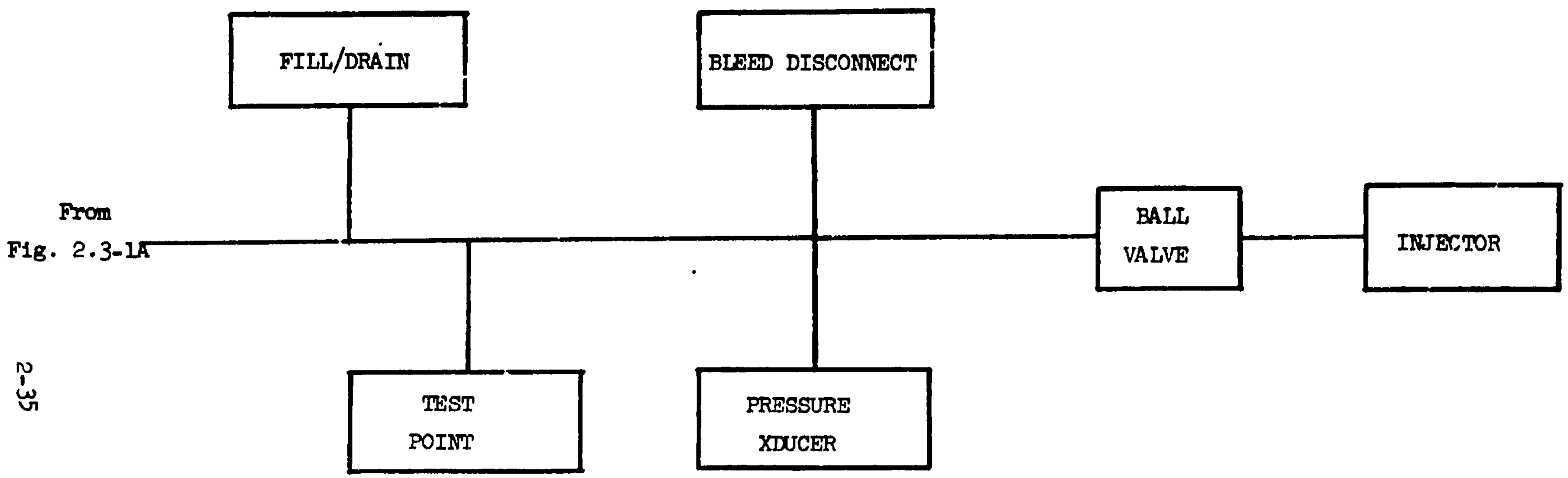


Figure 2.3-1B APS Oxidizer System

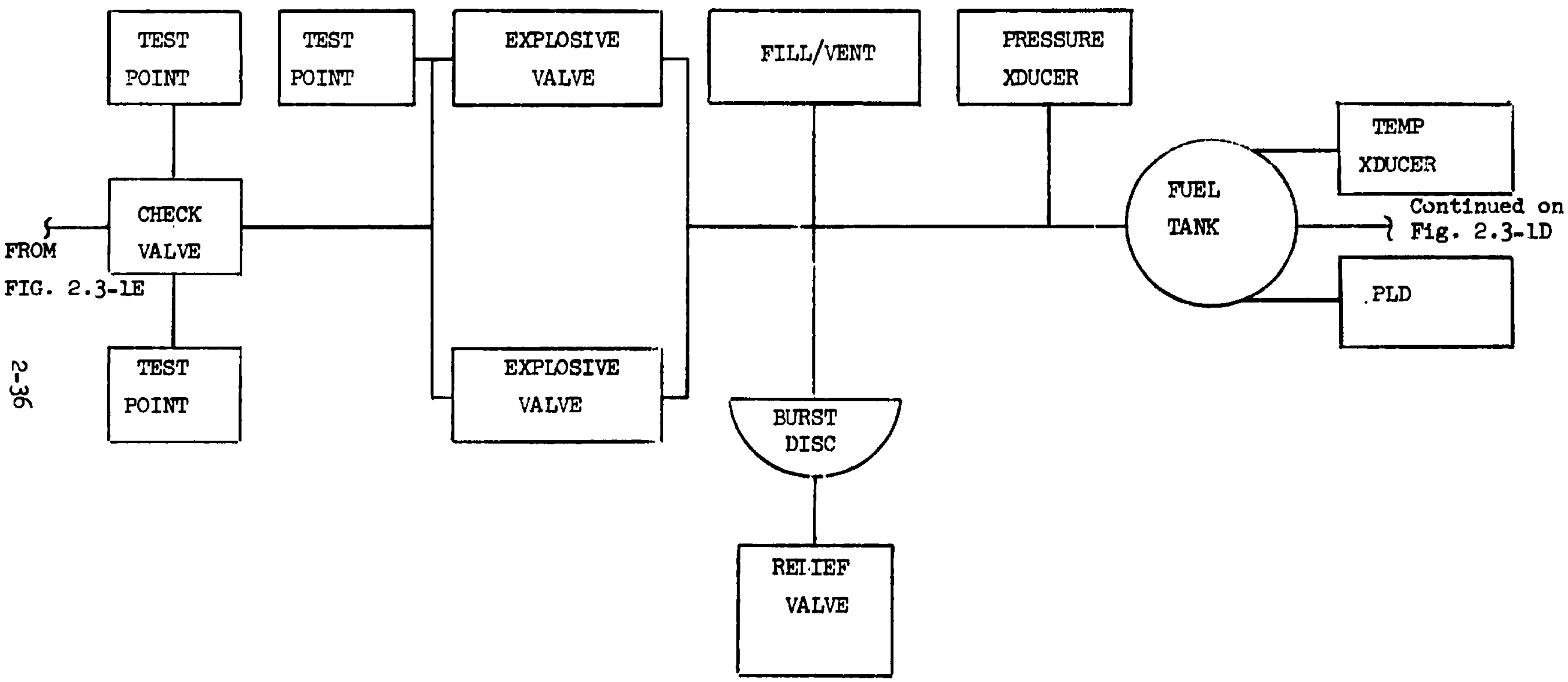


Figure 2.3-1C APS Fuel System

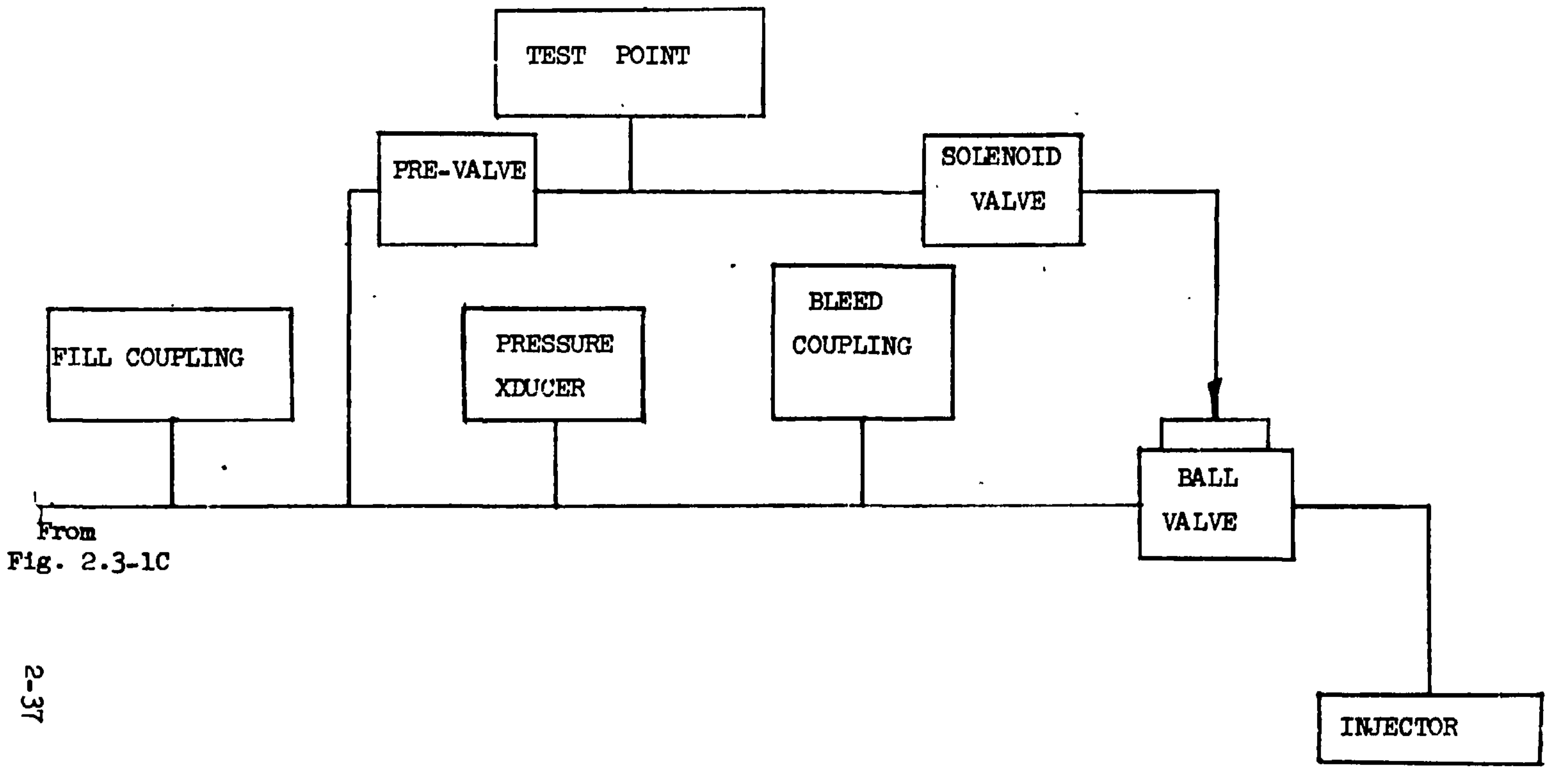


Figure 2.3-1D APS Fuel System

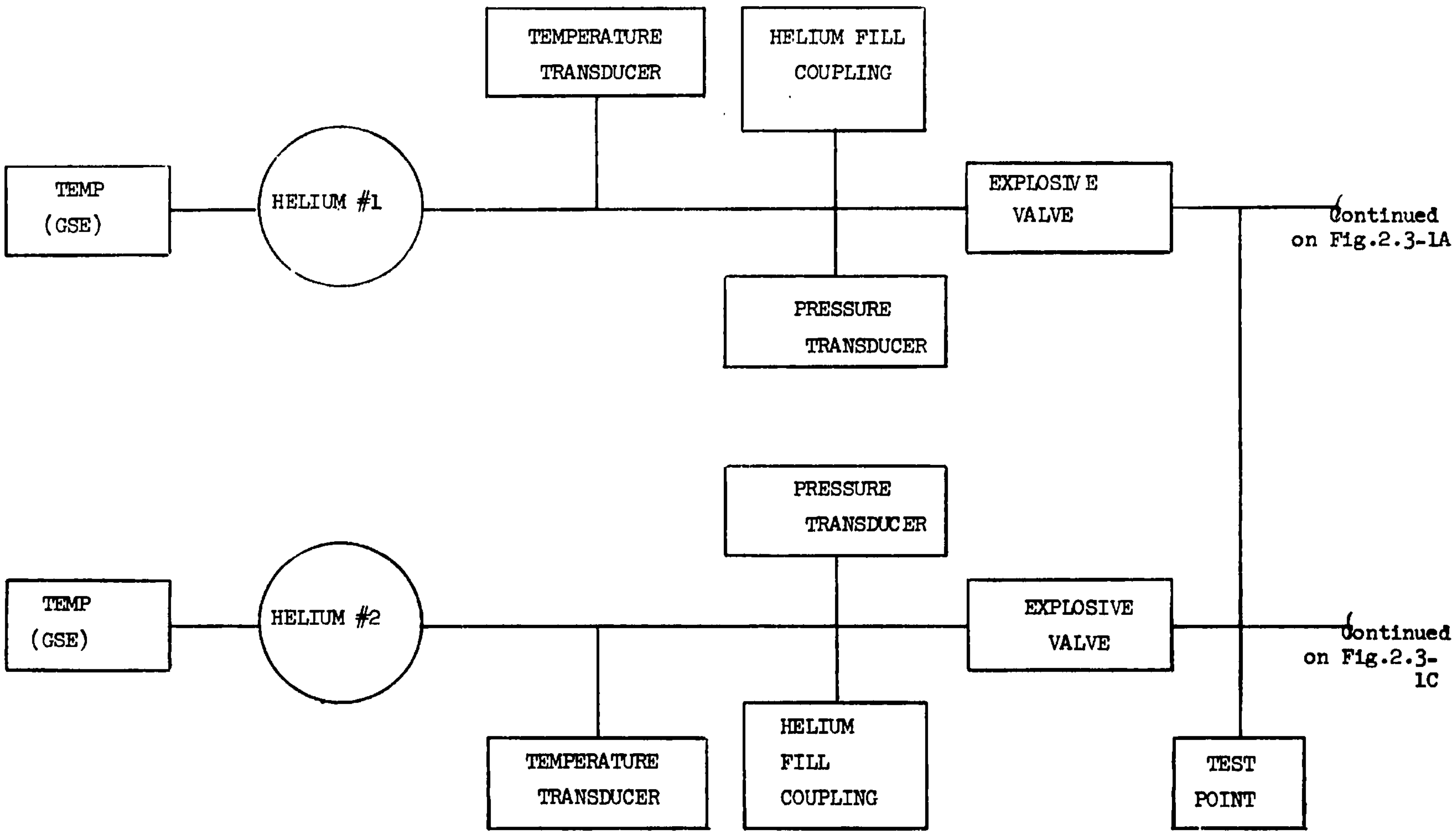


Figure 2.3-1E APS Helium System

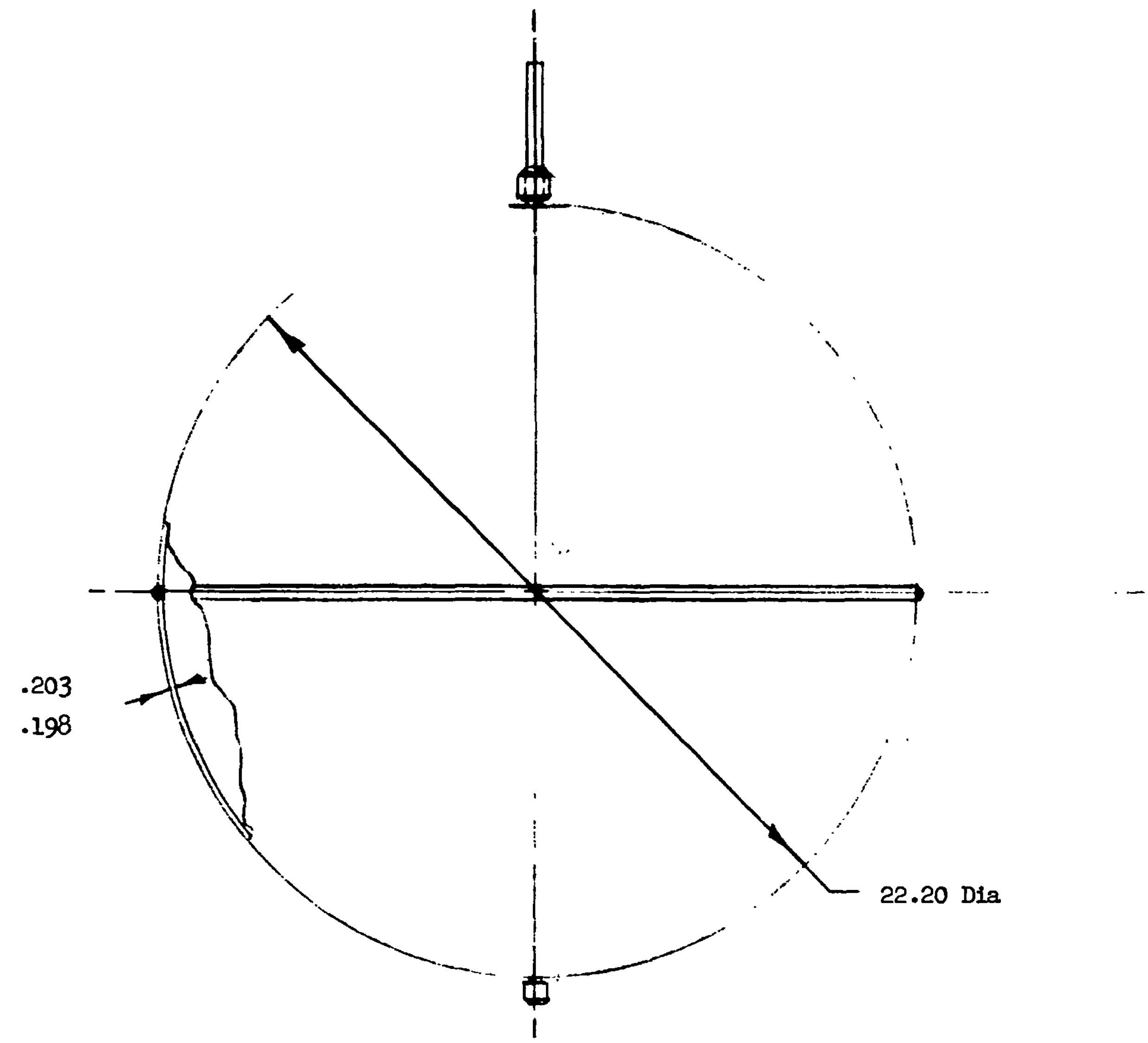
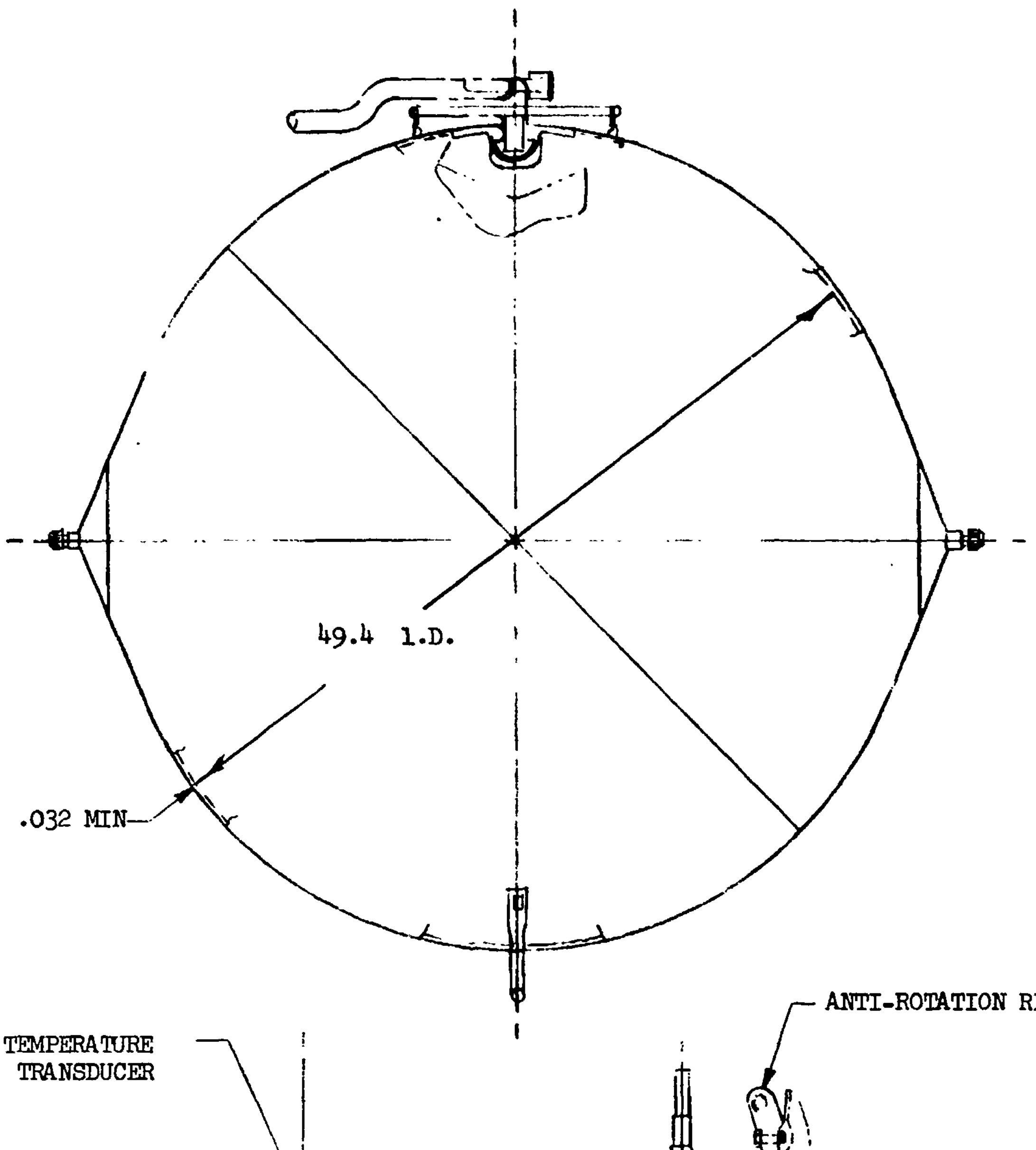
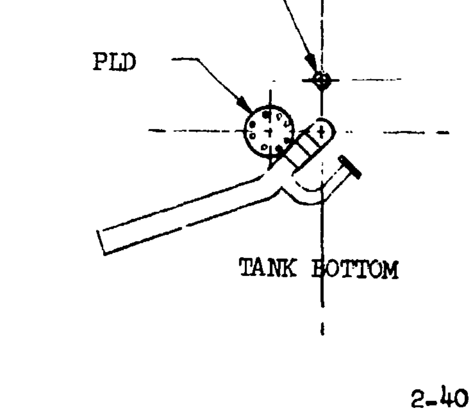


Figure 2.3-2 APS Helium Tank





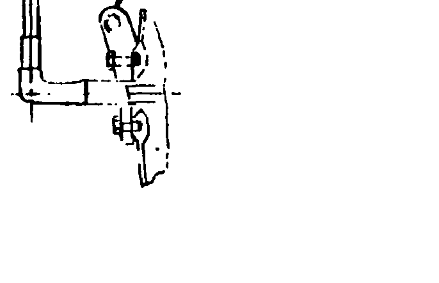


Figure 2.3-3 APS Propellant Tank

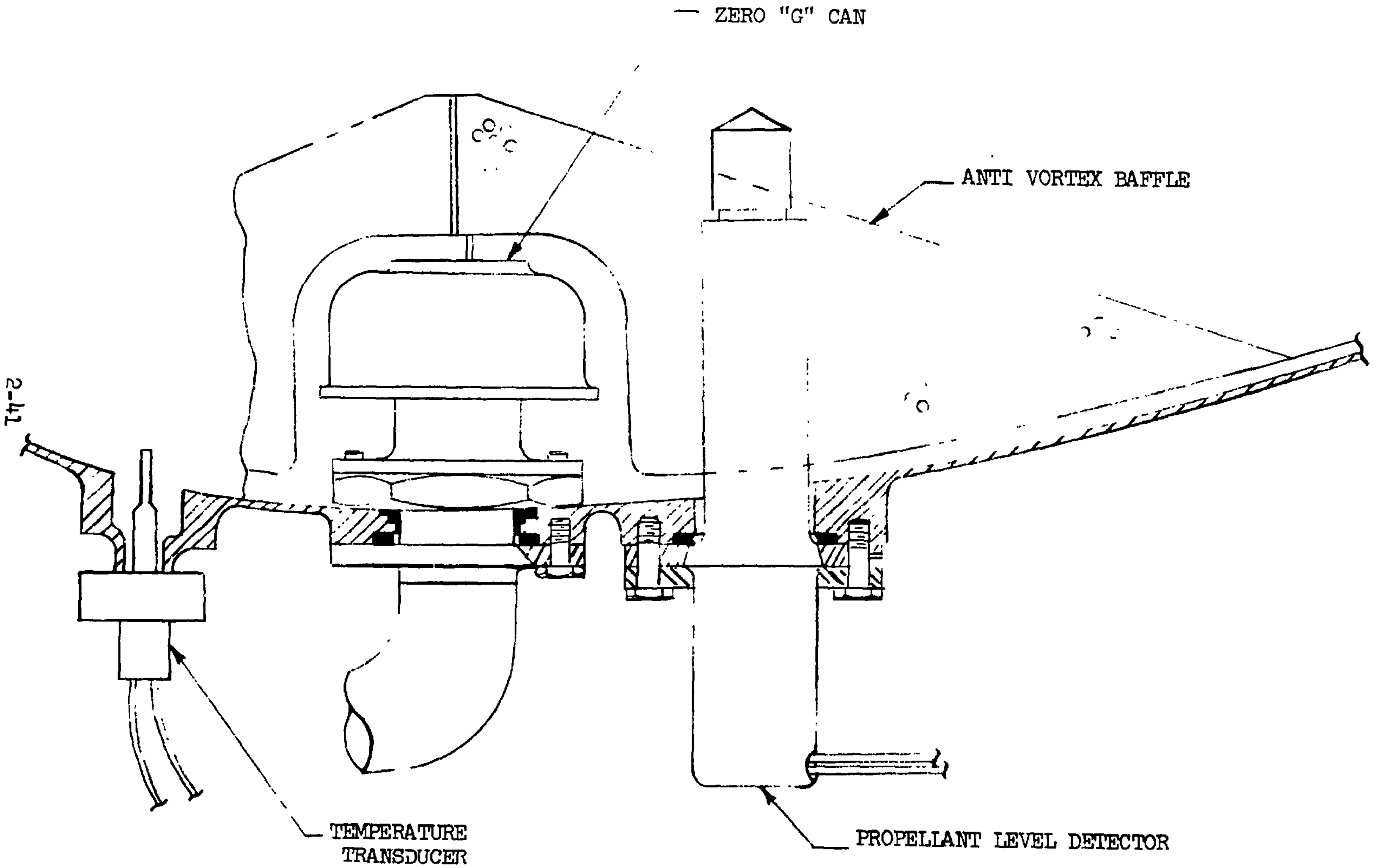


Figure 2.3-4 Tank Bottom, APS Propellant Tank

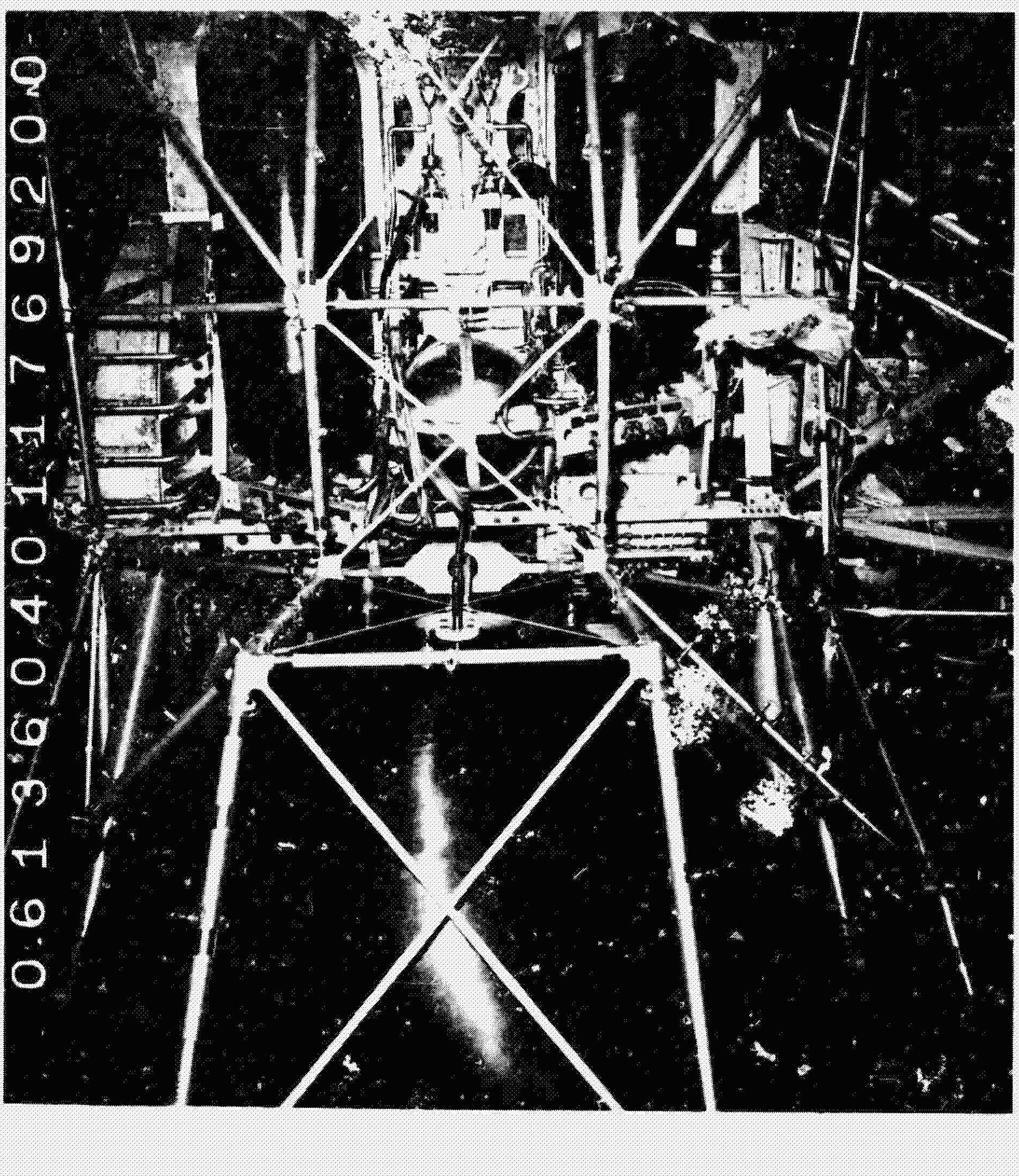


Figure 2.3-5 APS Fuel Tank, RCS Propellant Tanks and Helium Tank

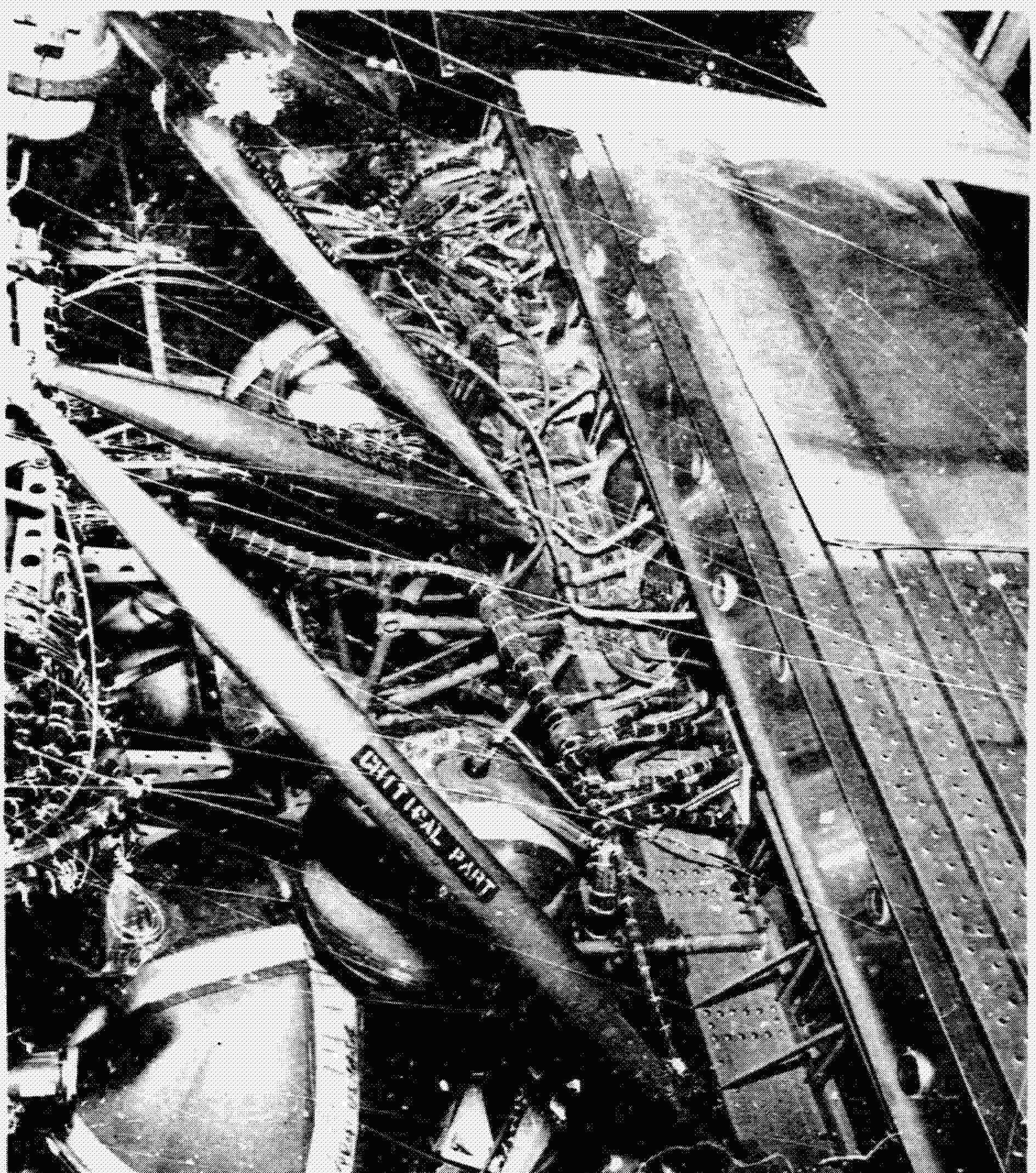


Figure 2.3-6 APS Helium Tanks and Ascent GOX Tanks

2.4 REACTION CONTROL SUBSYSTEM

The RCS configuration is shown schematically in Figure 2.4-1. Within the RCS there are two independent systems (A and B), each containing its own Helium, Propellant and Thrust Chamber Assembly (TCA) Sections. Figure 2.3-5 shows the installation of a RCS module (upper three tanks).

Helium is stored as a gas in a spherical titanium tank (see Figure 2.4-2). The propellant quantity measuring device is installed on one end of the He tank. An external black box, located above the helium tank near the oxidizer tank, computes propellant remaining by measuring pressure and temperature of the helium in the tank. A pressure transducer is located on the inlet-outlet port of the tank. Two redundant explosively operated, normally closed, squib valves seal the helium tank until just prior to separation from the CSM.

Two line-sensed regulators are installed in series downstream of the helium squib valves and upstream of the quad check valves. The first regulator is normally in operation and regulates helium pressure to 181 psi. Should this regulator fail open, the second regulator will take over regulating pressure to 185 psi. A pressure transducer is installed downstream of the regulator in both systems (A and B) in order to monitor the regulator outlet - propellant tank pressure. A parallel-series quad check valve is located in each branch leading to the propellant tanks to ensure isolation of one tank from the other. A relief valve is situated close to each helium port on the propellant tanks and is set to relieve at 232 psi. The relief valve consists of a burst disc, filter and relief mechanism. The burst disc ensures a sealed helium section during normal operation and will burst at 220 psi. No RCS helium pressurization system change was made as a result of the LM-10 configuration.

Each propellant section consists of two cylindrical titanium tanks with hemispherical ends (see Figure 2.4-3). The propellants are contained within a teflon bladder supported by a standpipe running length-wise in the tank. The standpipe is used to load and expel propellants. The helium pressurant flows between the bladder and the tank wall for positive expulsion.

A temperature transducer, located on the fuel tank outlets, monitors the tankage module temperature. A normally-open, latch-type, solenoid operated shut-off

2.4 cont'd

valve is situated downstream of the tank feed port for tank isolation (main shut-off valve). A ground test point is introduced here for line, valve and thruster checkout. From this point the propellant flows into a manifold feeding eight thrust chamber assemblies. A pressure transducer on each manifold indicates propellant pressure.

The manifolds of like propellant from each system can be connected through the opening of normally-closed, latch-type solenoid operated shut-off valves (crossfeed valves). Ascent engine propellant from the feed lines may be introduced into the RCS propellant manifolds through the actuation of normally-closed, solenoid operated, latch-type shutoff valves called secondary valves. Another set of valves (primary) are placed in series with the secondary valves and are normally open (RCS/APS interconnect valves). The primary valves are redundant and would be used to close off the lines should the secondary valves fail open. Actuation of these valves provides propellant to either one or both manifolds. Propellant filters are located between the ascent propulsion subsystem and the interconnect valves. No propellant feed system change was made as a result of LM-10 configuration.

Each independent system feeds eight thrust chamber assemblies, two TCA's in each cluster, ensuring control in all axes. The lines feeding these two TCA's may be closed by normally-open solenoid valves (isolation valves). On LM-10 and subsequent, the isolation valves have been removed. The TCA's are grouped into clusters of four (quads). Each cluster has redundant heaters for the purpose of maintaining the engines at a correct operating temperature level both in-flight and on the lunar surface. A temperature sensor is located in each cluster for the purpose of monitoring engine temperature.

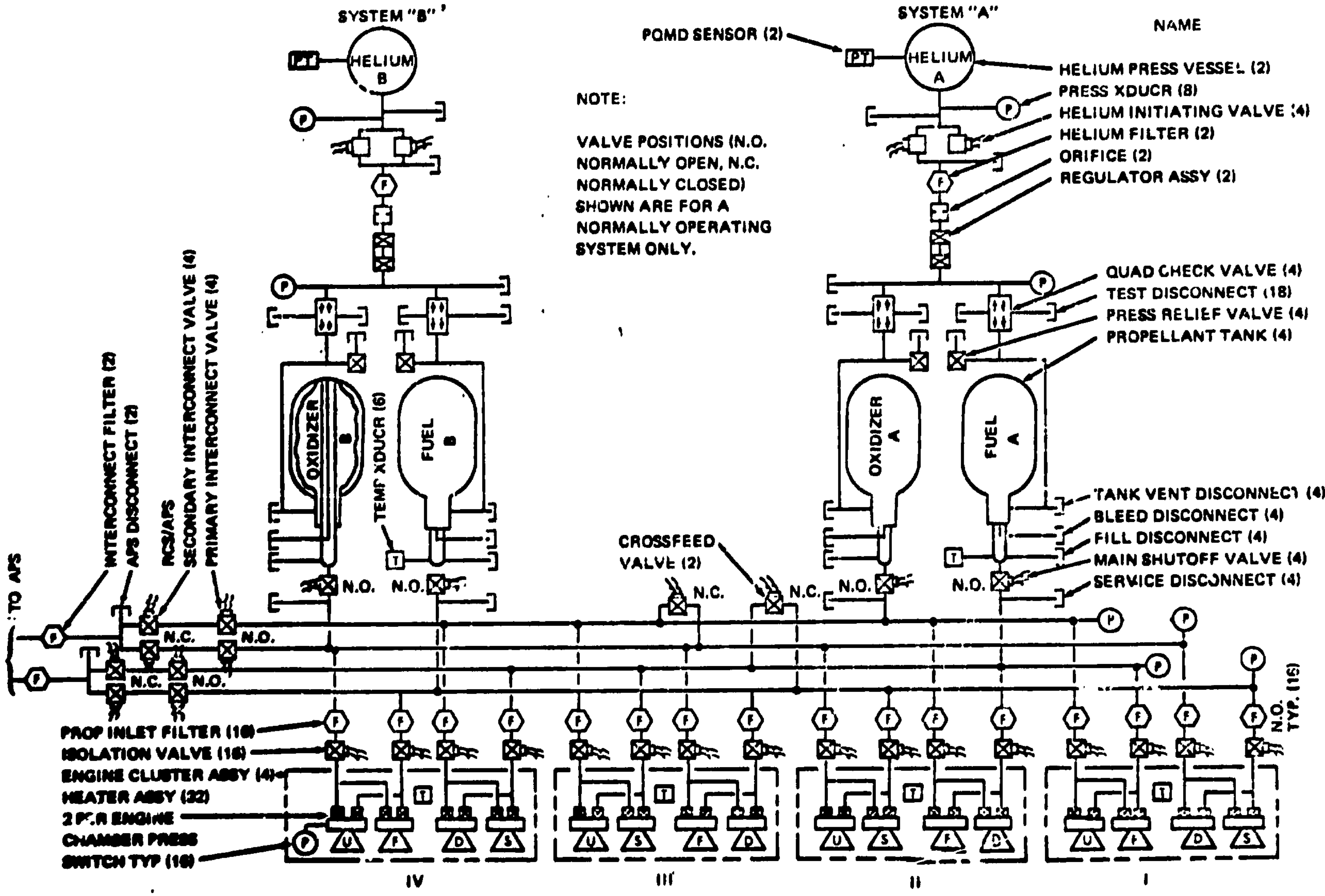


Figure 2.4-1 RCS Schematic

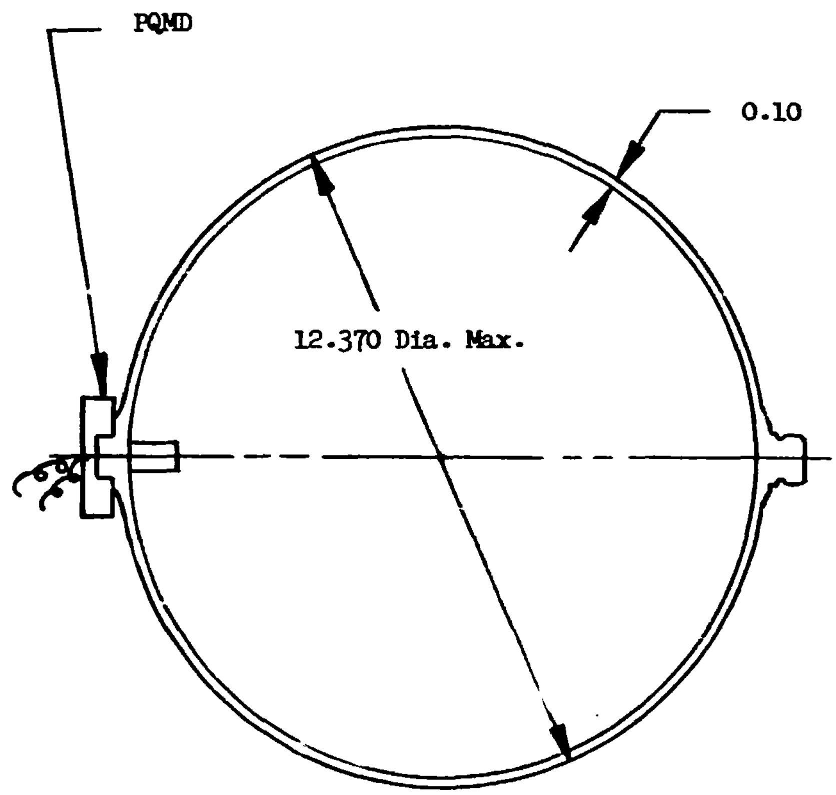


Figure 2.4-2 RCS Helium Tank

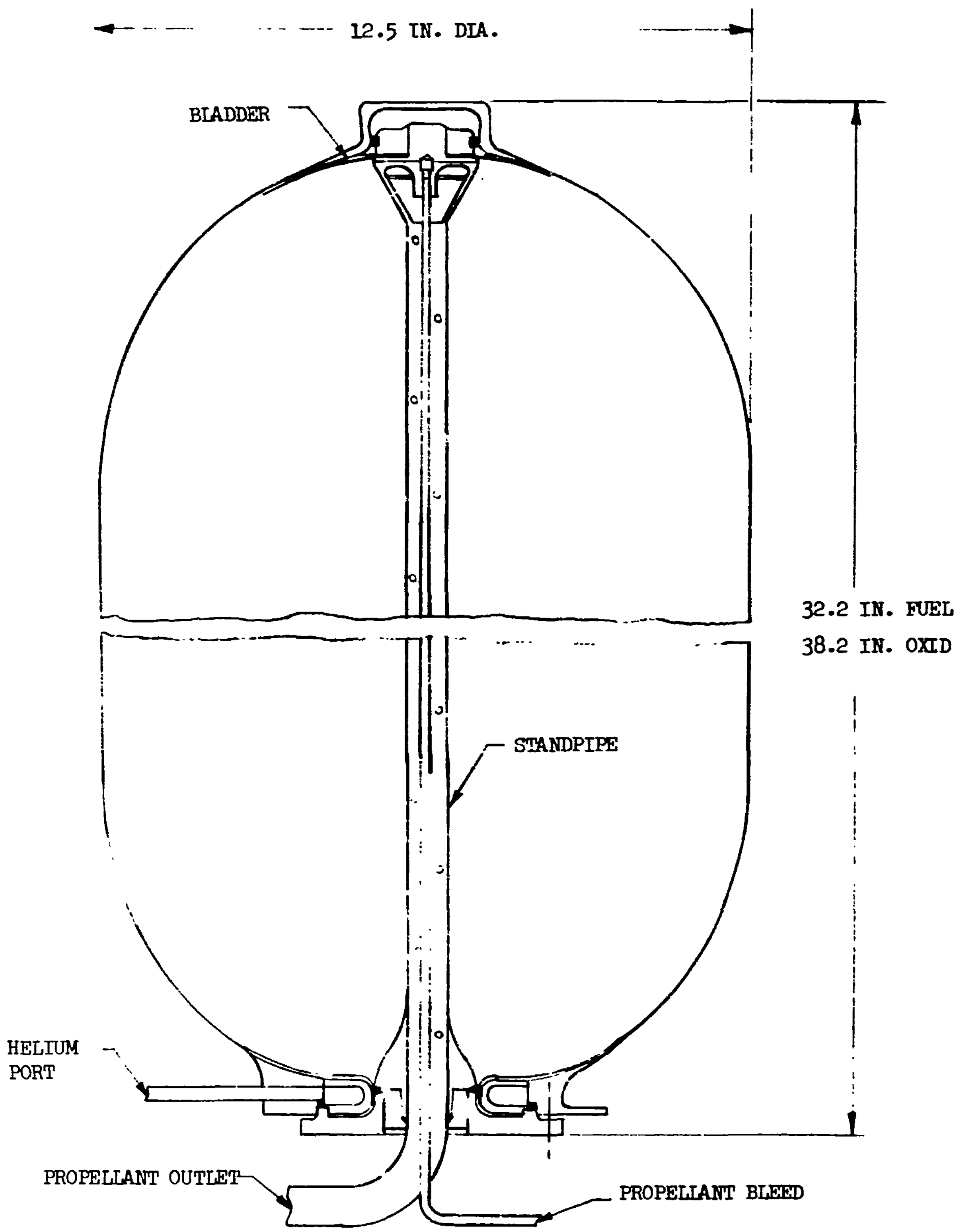


Figure 2.4-3 RCS Propellant Tank

2.5 ENVIRONMENTAL CONTROL SUBSYSTEM

2.5.1 Oxygen Supply Section

The Oxygen Supply Section (shown schematically in Figure 2.5-1) stores, in gaseous form, all oxygen required by the LM and maintains cabin or suit-pressurization by supplying oxygen in sufficient quantities to replenish losses due to crew metabolic consumption and cabin/suit leakage. This section also provides for PLSS oxygen refills.

The descent stage oxygen tank (Figure 2.5-2) provides all required LM oxygen from earth launch through switch over to ascent stage oxygen supplies. The Quad-III installation is shown in Fig. 2.2-6 (upper left tank). In the LM-10 configuration, an additional descent stage oxygen tank is located in Quad IV (see Figure 2.5-3; upper tank). Check valves are included in this configuration to provide tank isolation. The oxygen lines in the system were revised to accommodate the additional oxygen components for the LM-10 configuration.

Two identical ascent stage oxygen tanks (Figure 2.5-4) provide all LM supplied oxygen subsequent to switchover to ascent consumables. The installation of the tanks in the aft equipment bay is shown in Figure 2.3-6 (two smaller tanks). The oxygen pressure from the oxygen control module is monitored by a pressure transducer located downstream of the module in the PLSS fill line. In the LM-10 and subsequent configuration this pressure transducer was deleted.

The oxygen high-pressure control assembly reduces the level of descent tank pressure (3000 psia) to a level compatible with the normal operation of the oxygen control module (1000 psia). The control assembly also provides high-pressure relief capability through relief valves, 1144 psig max., and burst diaphragm, 1400 psig max.

The oxygen control module controls the supply of O_2 to the atmosphere revitalization section (5 psia and 3.5 psia), to the cabin for emergency repressurization (5 psia) and to the PLSS recharge assembly (1000 psia). The module also controls the oxygen supply flow rate.

The PLSS oxygen fill assembly provides a flexible hose and self-sealing disconnect for refilling of the PLSS primary oxygen storage tank. On LM-10, the high

2.5.1 cont'd

pressure oxygen PLSS refill module reduces the descent tank pressure level (3000 psia) to a level compatible with that of the higher pressure PLSS oxygen storage tank (1450 psia). The high pressure relief capability is provided by a relief valve with a 1575 psig max relief pressure. A new interstage disconnect was added downstream of the high pressure oxygen PLSS refill module for the LM-10 and subsequent configuration. A PLSS oxygen fill valve is also installed on LM-10 and subsequent to provide shutoff capability to the higher pressure PLSS refill section.

2.5.2 Water Management Section

The Water Management Section (shown schematically in Figure 2.5-5) provides for storage and distribution of water used in the LM for evaporative cooling, metabolic consumption by the crew, and PLSS refill.

The descent stage water tank (Figure 2.5-6) provides all water required by the LM prior to staging. The tank provides positive expulsion of the water by the use of a bladder and standpipe design. The tank is pressurized to 47 psia with nitrogen prior to earth launch. Installation of the tank in Quad II is shown in Figure 2.5-7. In the LM-10 configuration, an additional descent stage tank is located in Quad IV (see Figure 2.5-3; lower tank). Check valves are included in this configuration to provide tank isolation.

Two identical ascent stage water tanks (Figure 2.5-8) provide all water required by the LM subsequent to switchover from descent stage water supplies. These tanks are also pressurized to 47 psia with nitrogen prior to earth launch. Installation of the -Y tank is shown in Figure 2.5-9.

Instrumentation in the ECS pressurized oxygen and water systems is limited to pressure transducers attached by threaded fittings (AN) on a line external to the tanks and water quantity measuring devices (WQMD) attached to the tanks. The location of the instrumentation with respect to the tanks is as follows:

- D/S O_2 pressure transducer - approx. 3 feet of line downstream from the tank
- A/S O_2 pressure transducer - approx. $1\frac{1}{2}$ feet of line downstream from the tank

2.5.2 cont'd

- o WQMD sensor - mounted on gas side of D/S and A/S water tanks. (effective through LM-8 only)
- o D/S Water pressure transducer - approximately 6 inches of line from the tank. A second lower pressure D/S water pressure transducer is located downstream approximately 5 feet of line from the tank. (These transducers are effective LM-9 and subsequent)
- o A/S water pressure transducers - approximately 3 feet of line from each tank (these transducers are effective LM-9 and subsequent).

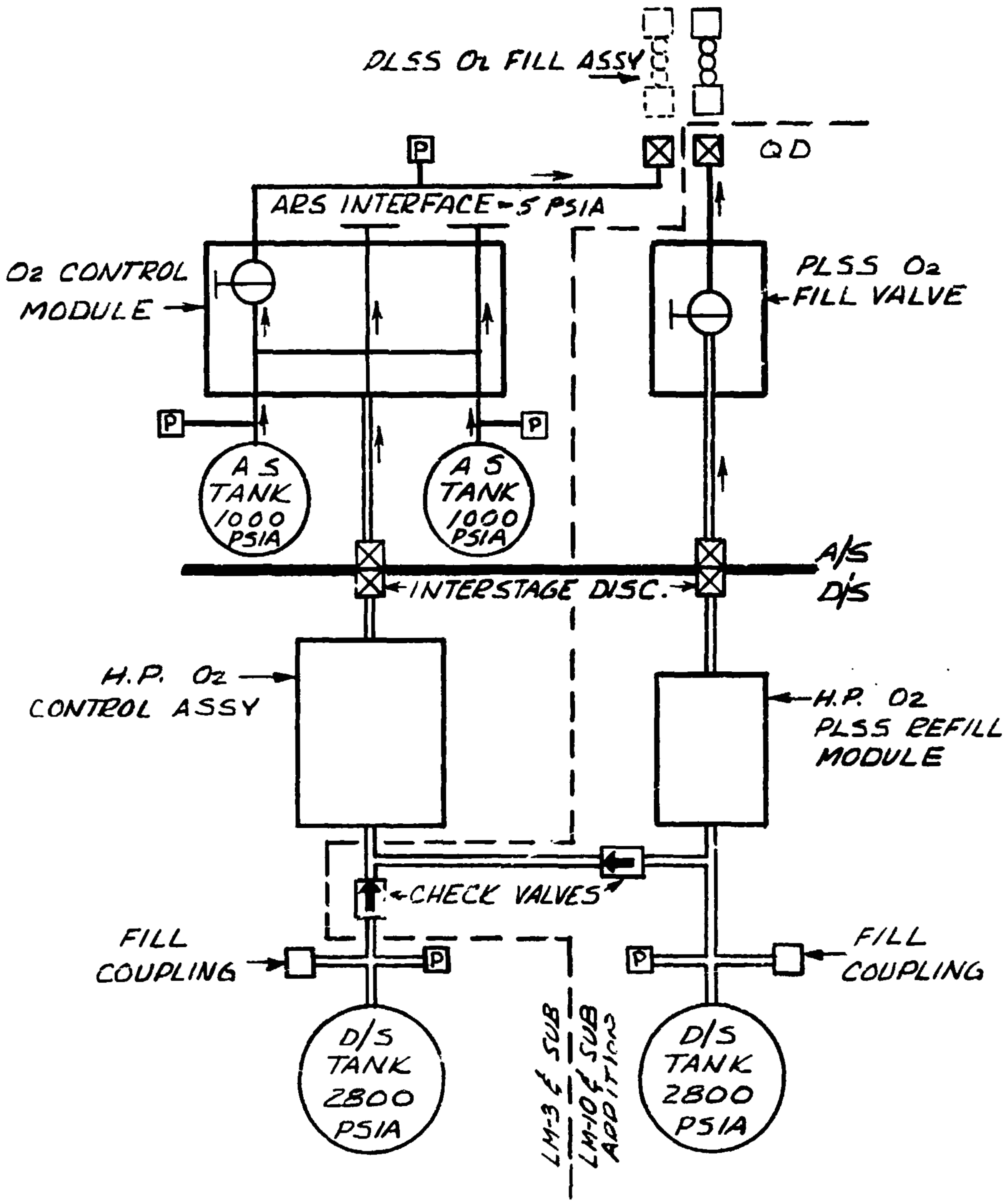


Figure 2.5-1 OXYGEN SYSTEM SCHEMATIC

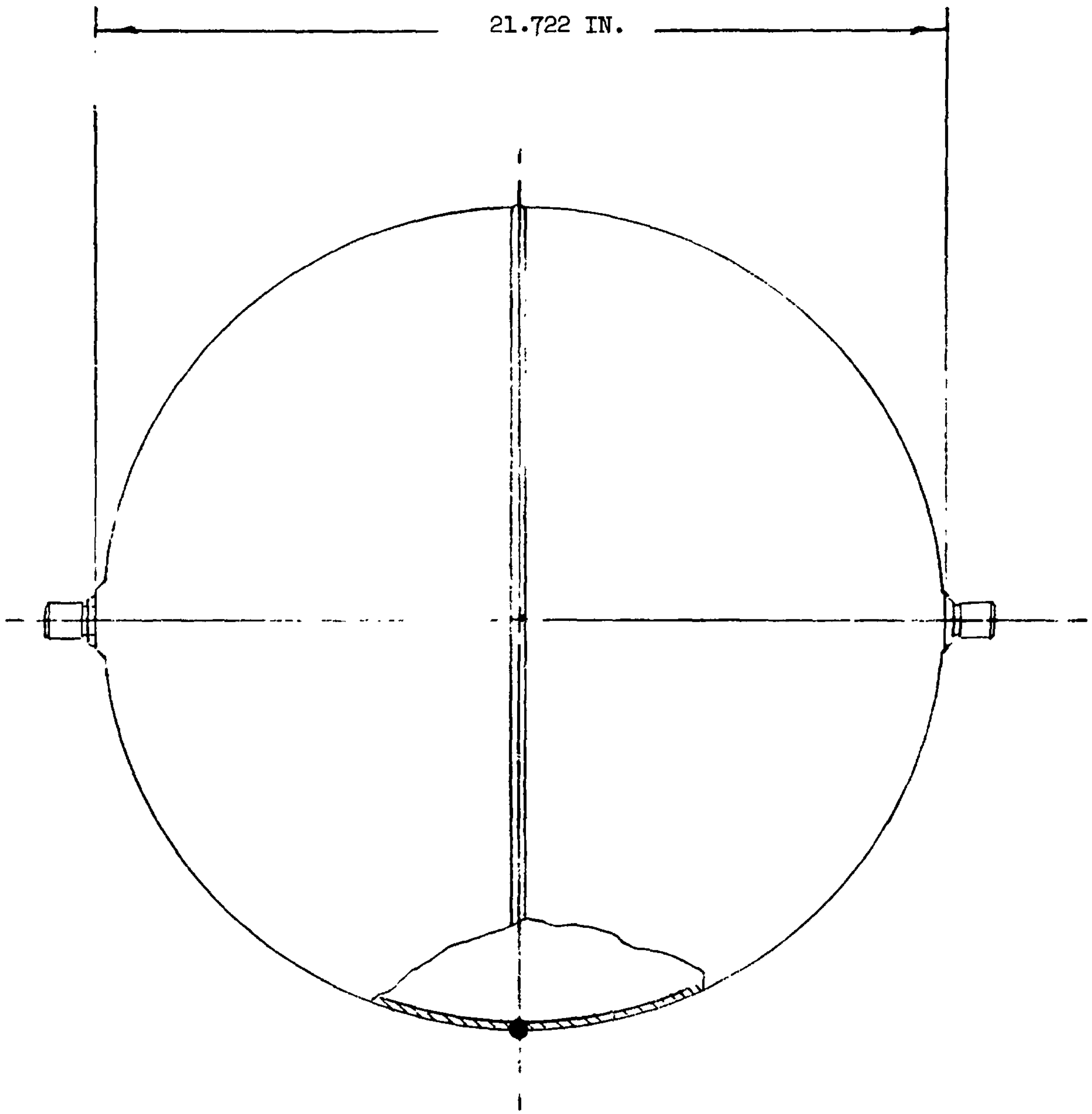


Figure 2.5-2 Descent Oxygen Tank

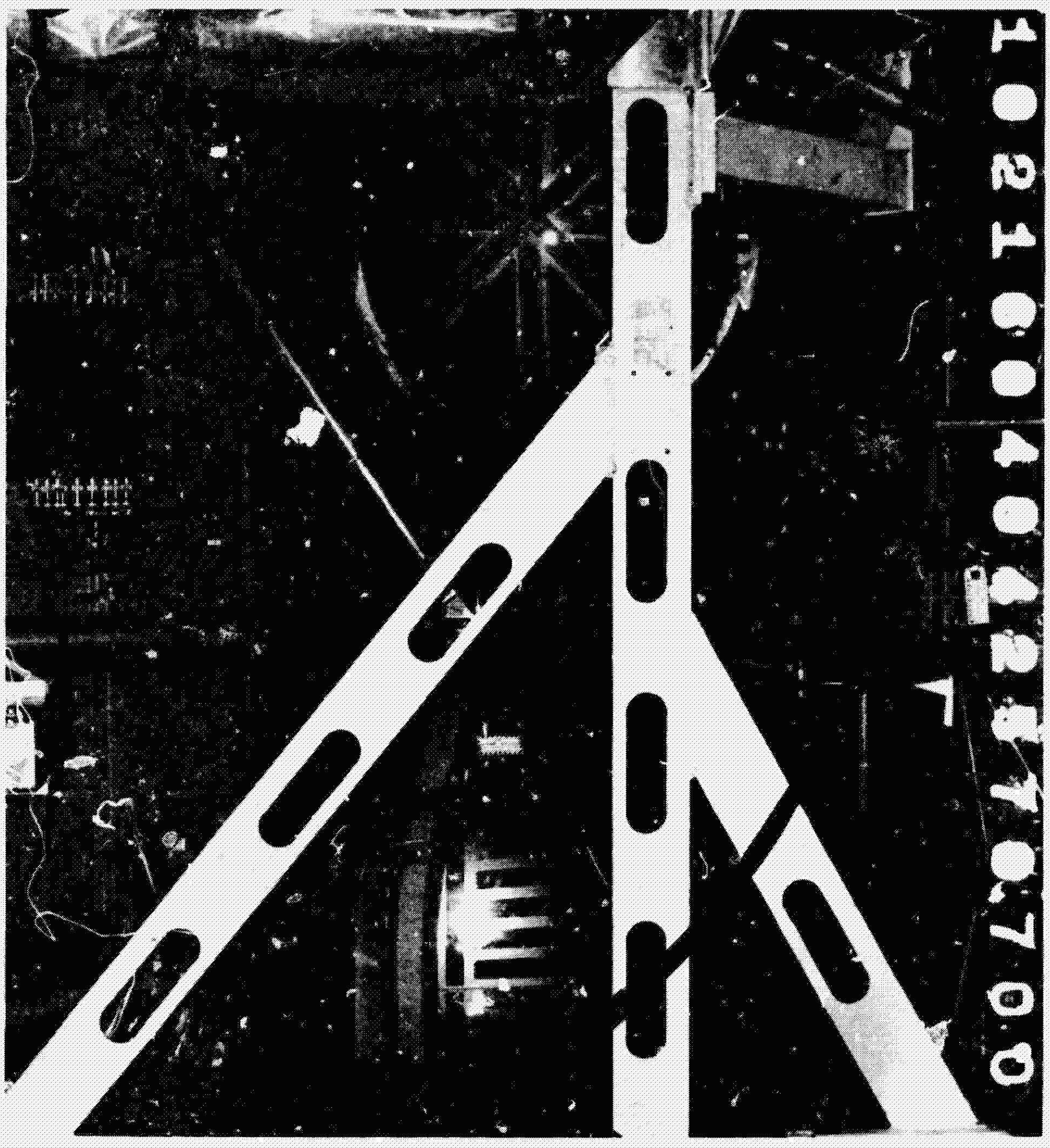


Figure 2.5-3 Descent Oxygen & Water Tanks, Quad IV (LM-10)

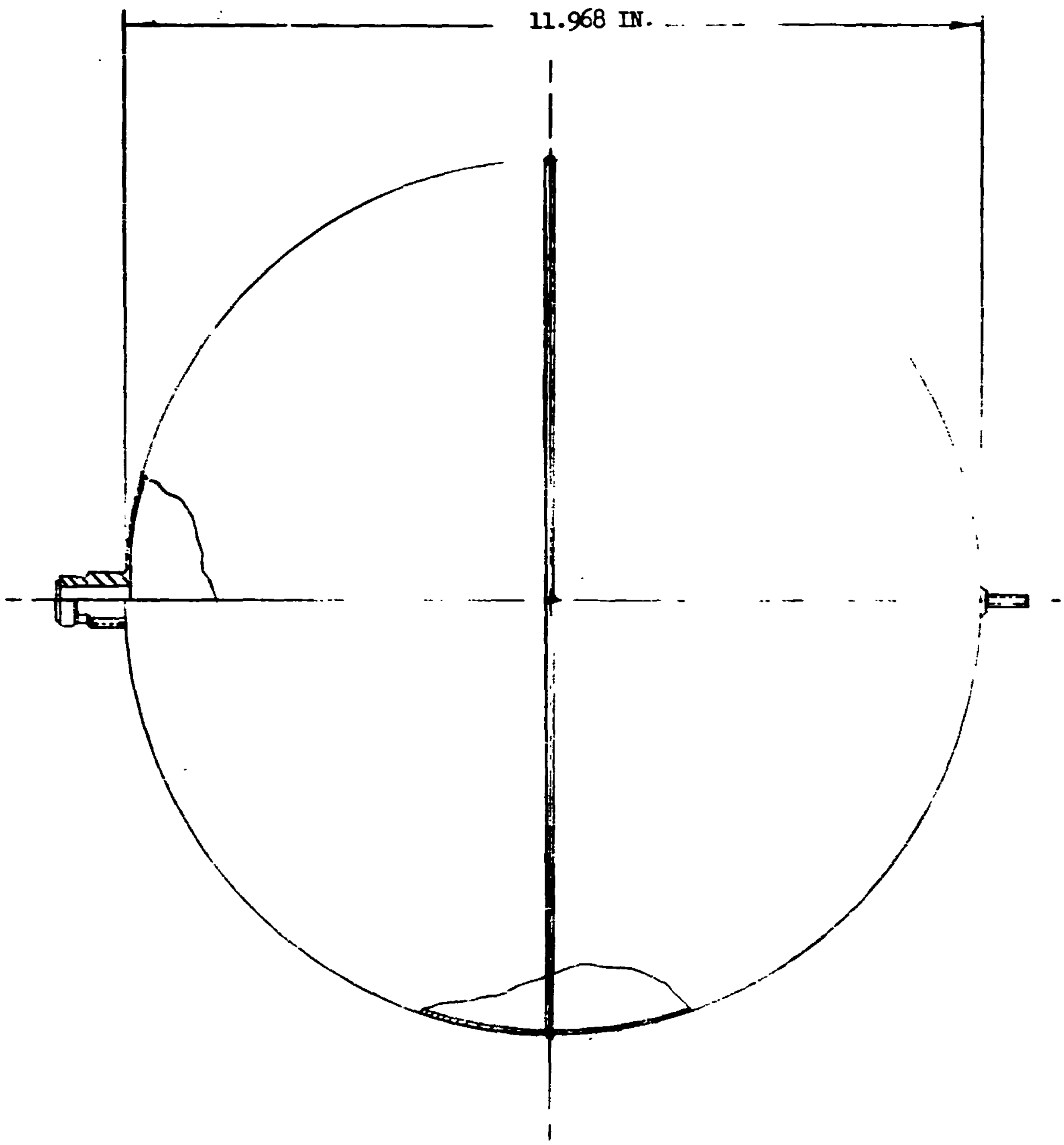


Figure 2.5-4 Ascent Oxygen Tank

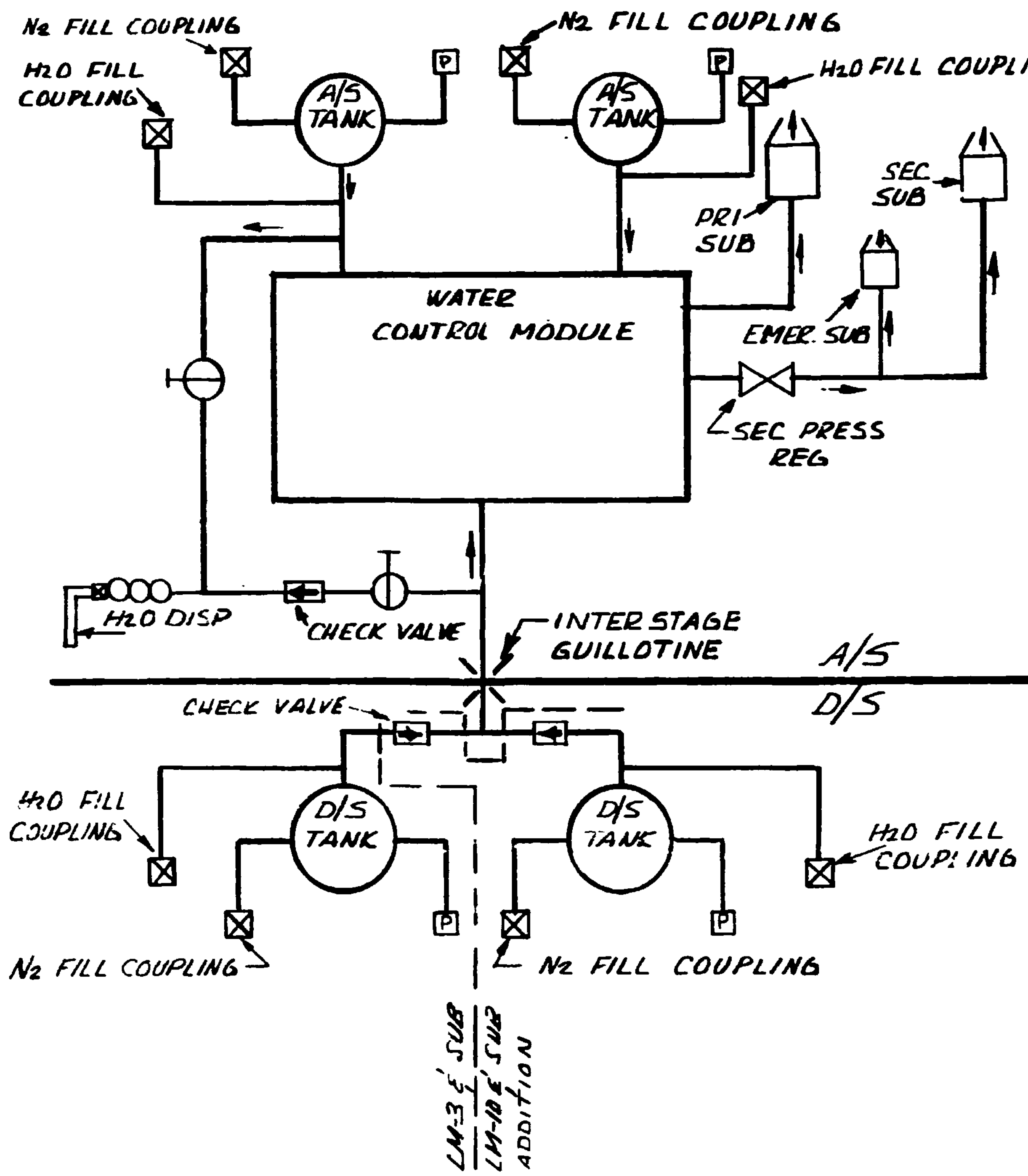


Figure 2.5-5 WATER MANAGEMENT SYSTEM SCHEMATIC

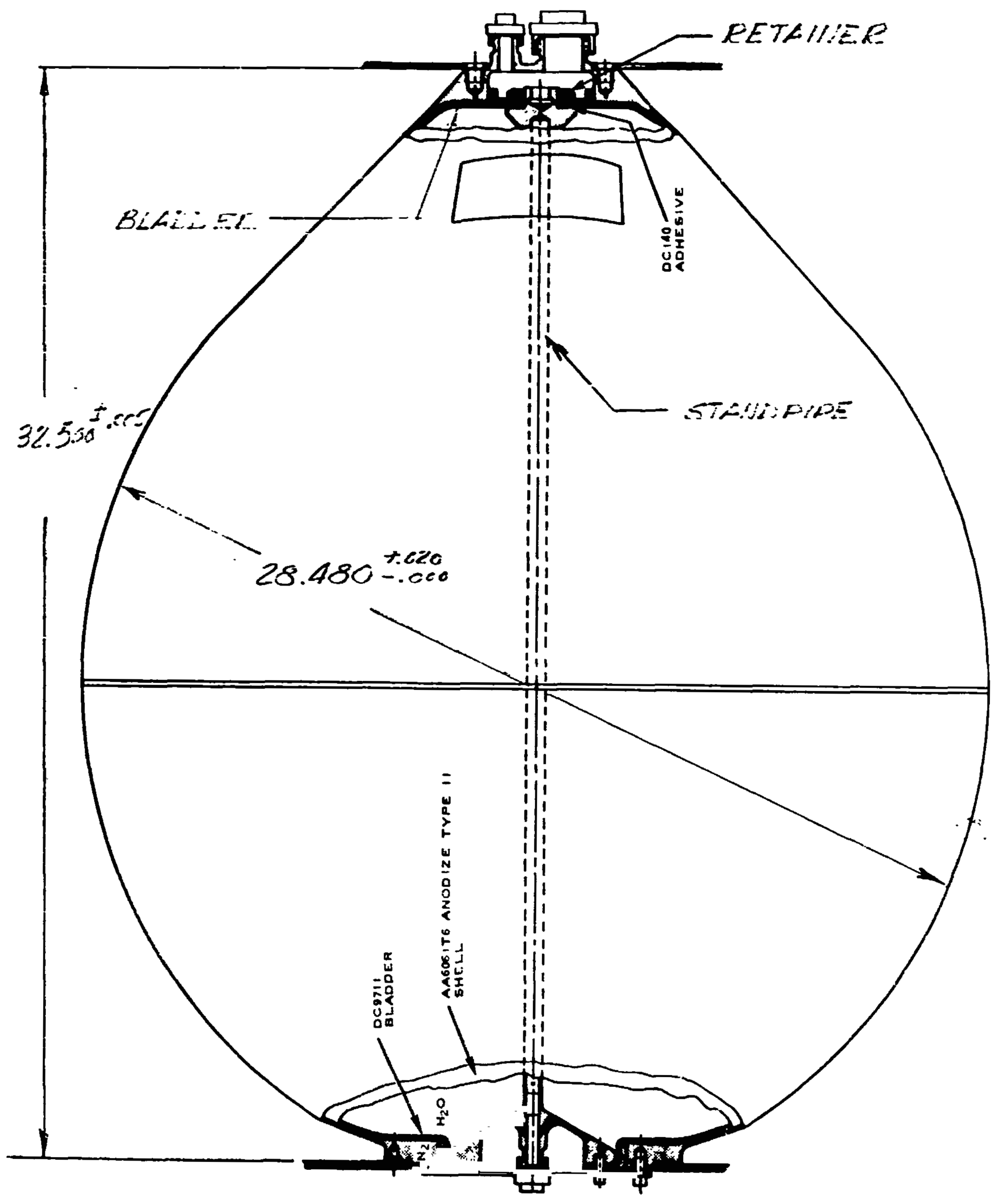


Figure 2.5-6 Descent Stage Water Tank

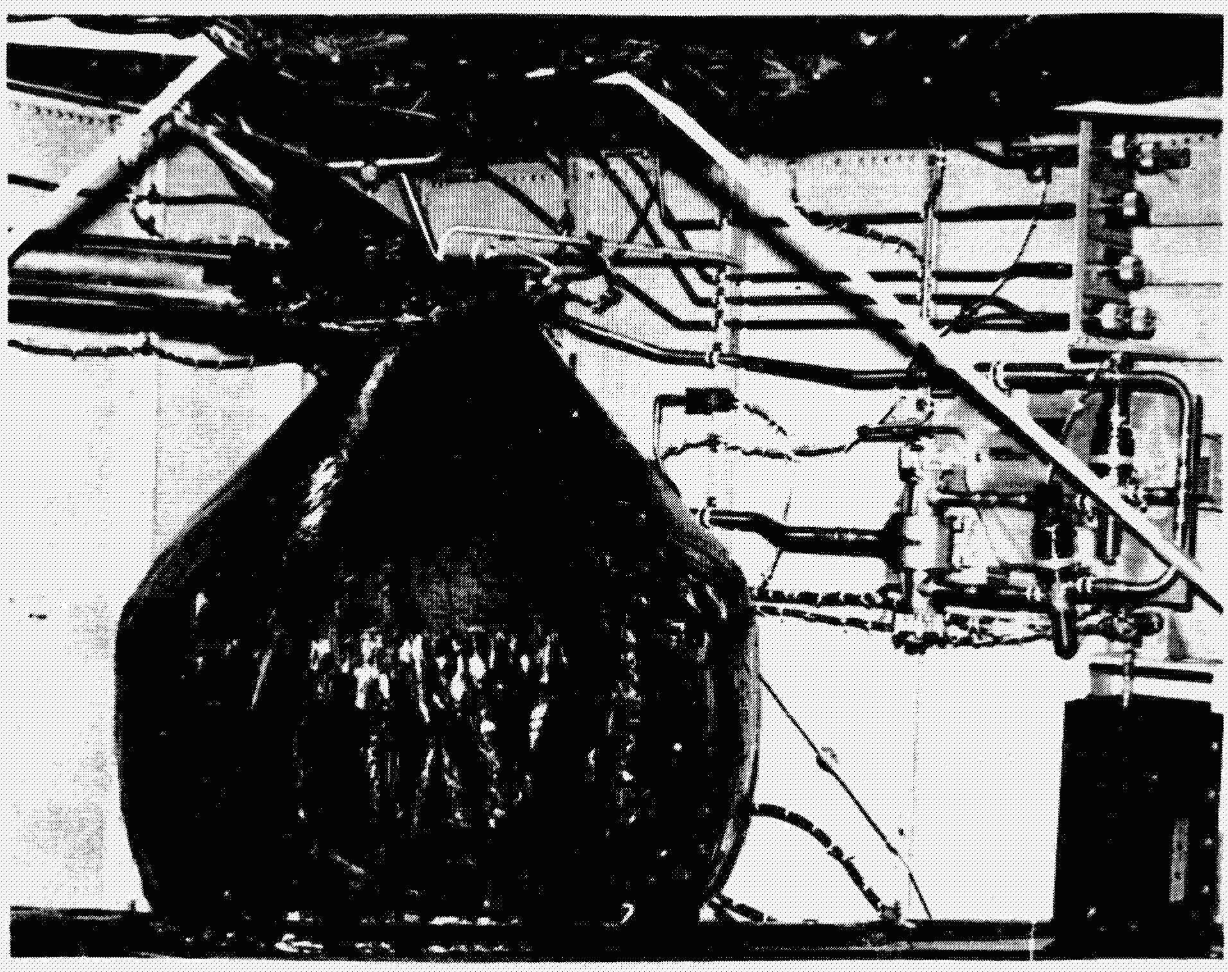


Figure 2.5-7   Descent Stage Water Tank, Quad II

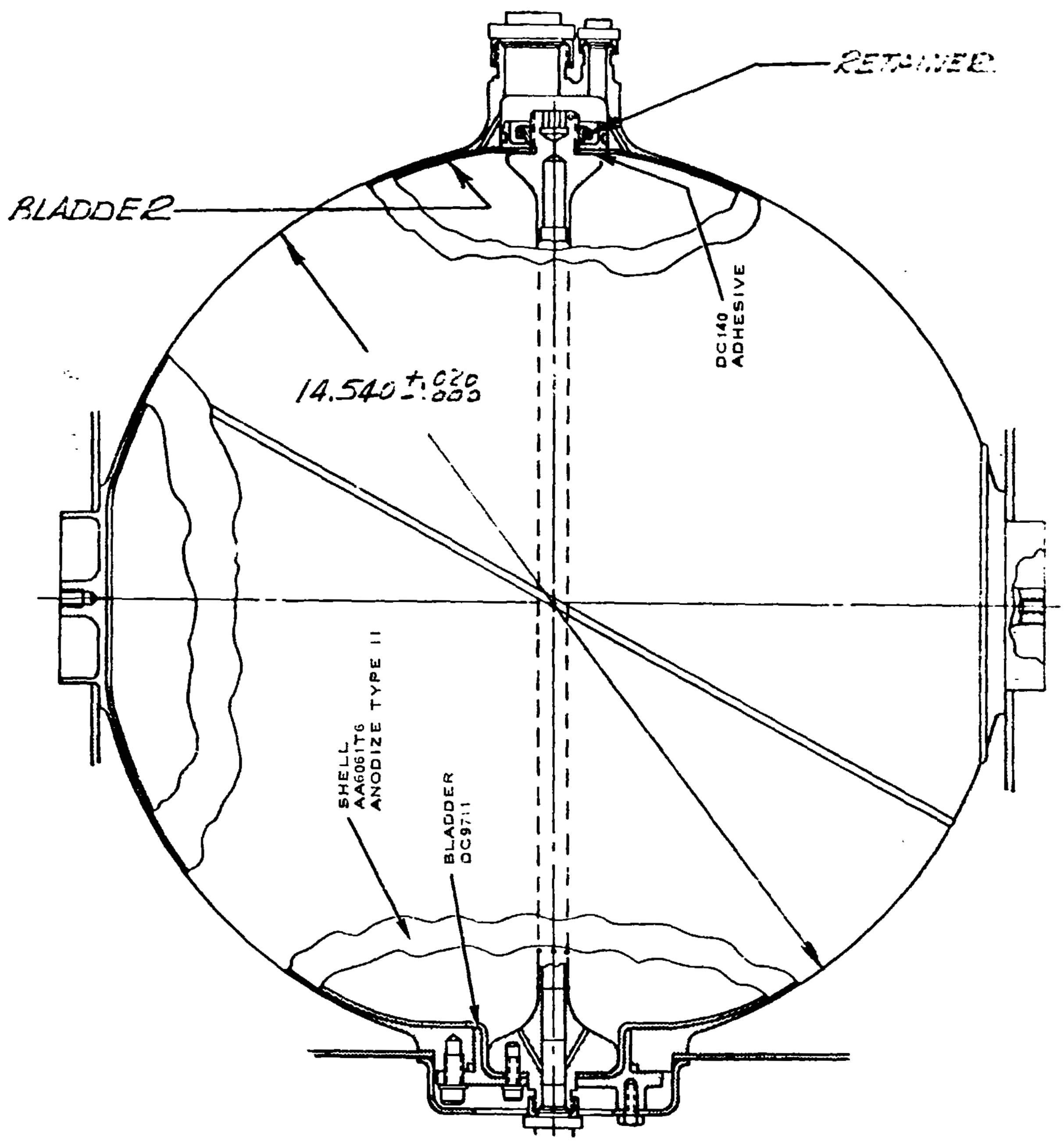


Figure 2.5-8 Ascent Stage Water Tank

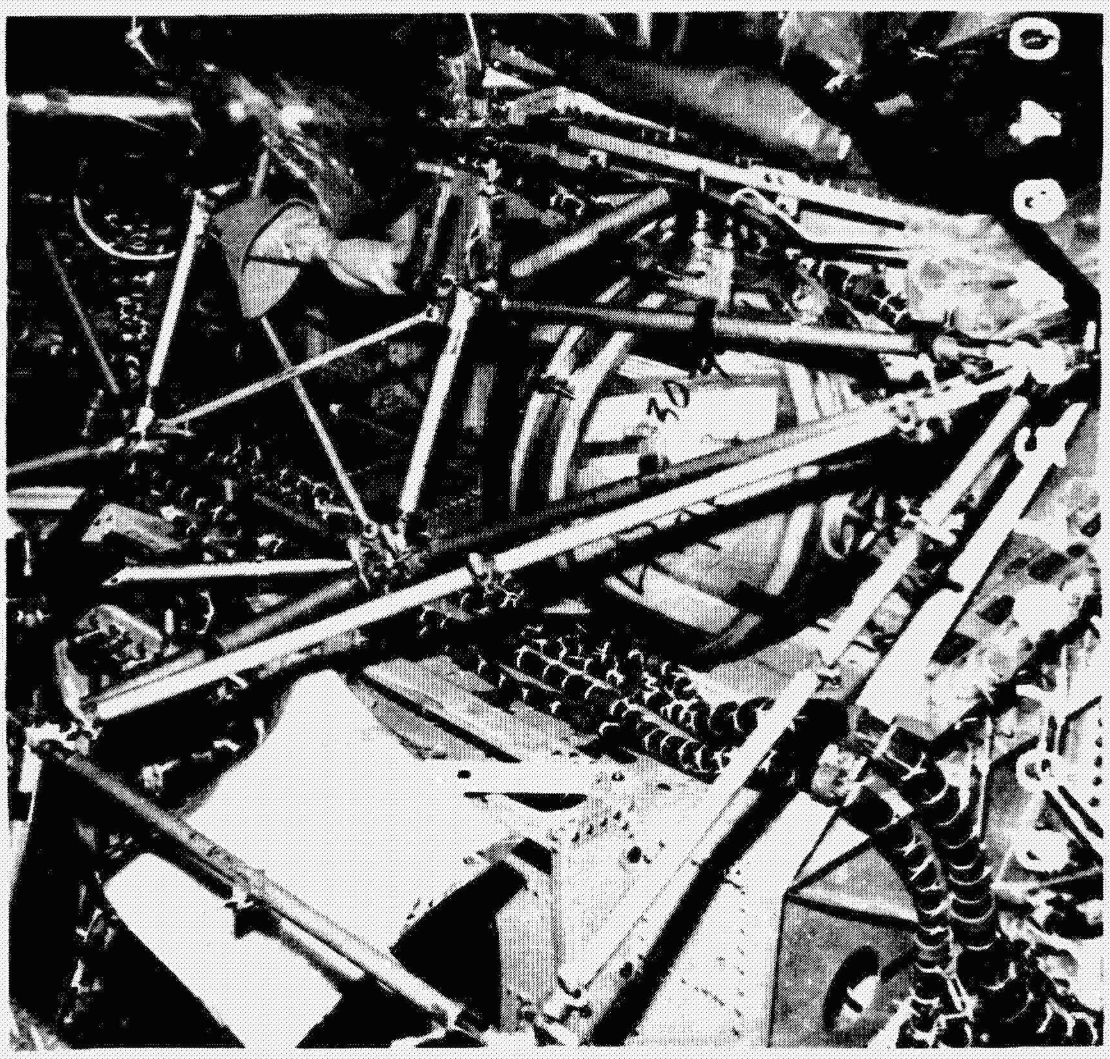


Figure 2.5-9 -Y Ascent Stage Water Tank

2.6 BATTERIES

The LM electrical power is provided by three battery types: Descent, Ascent and Explosive Devices (Fig. 2.6-1, 2.6-2 and 2.6-3 respectively). The Descent and Ascent batteries serve as the prime power source, while the Explosive Devices (ED) batteries fire the pyrotechnic systems.

The batteries are described in Table 2.1-1 and are shown in their relative positions with respect to the descent and ascent stages in Figures 2.1-3, 2.1-5 and 2.1-12. Table 2.6-1 summarizes the electrical characteristics for each battery.

The main batteries are monitored during malfunction only. Normally opened bimetalic thermal switches are provided, 5 in the descent stage batteries and 10 in the ascent stage batteries, with parallel wiring. When a battery temperature increases to 140 to 150°F, the thermal switches actuate sending a signal to the LM cabin master alarm and caution and warning system indicating a battery malfunction.

The open circuit voltages of the ED batteries are monitored in the cabin: these measurements are not telemetered.

TABLE 2.6-1

BATTERY ELECTRICAL CHARACTERISTICS

ELECTRICAL DATA	PRIMARY ASCENT	PRIMARY DESCENT	ED
Voltage (Open Circuit)	37.0 VDC	37.0 VDC	37.1 VDC
Ampere hour/battery	296 A-Hmin.	400 A-H min.	.75 A-H
Number cells/battery	20	20	20
Number of batteries	2	4	2

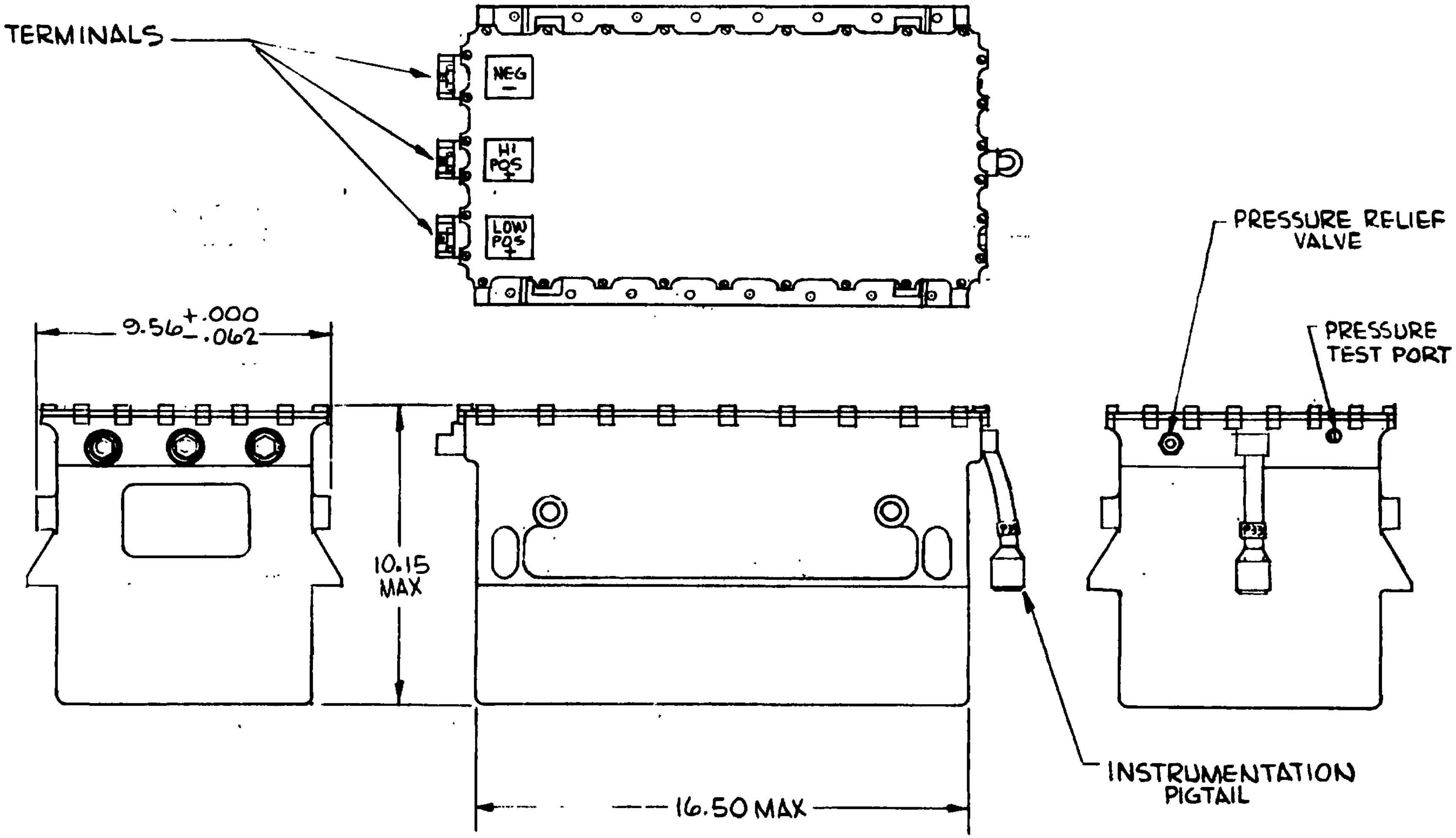


Figure 2.6-1 DESCENT BATTERY

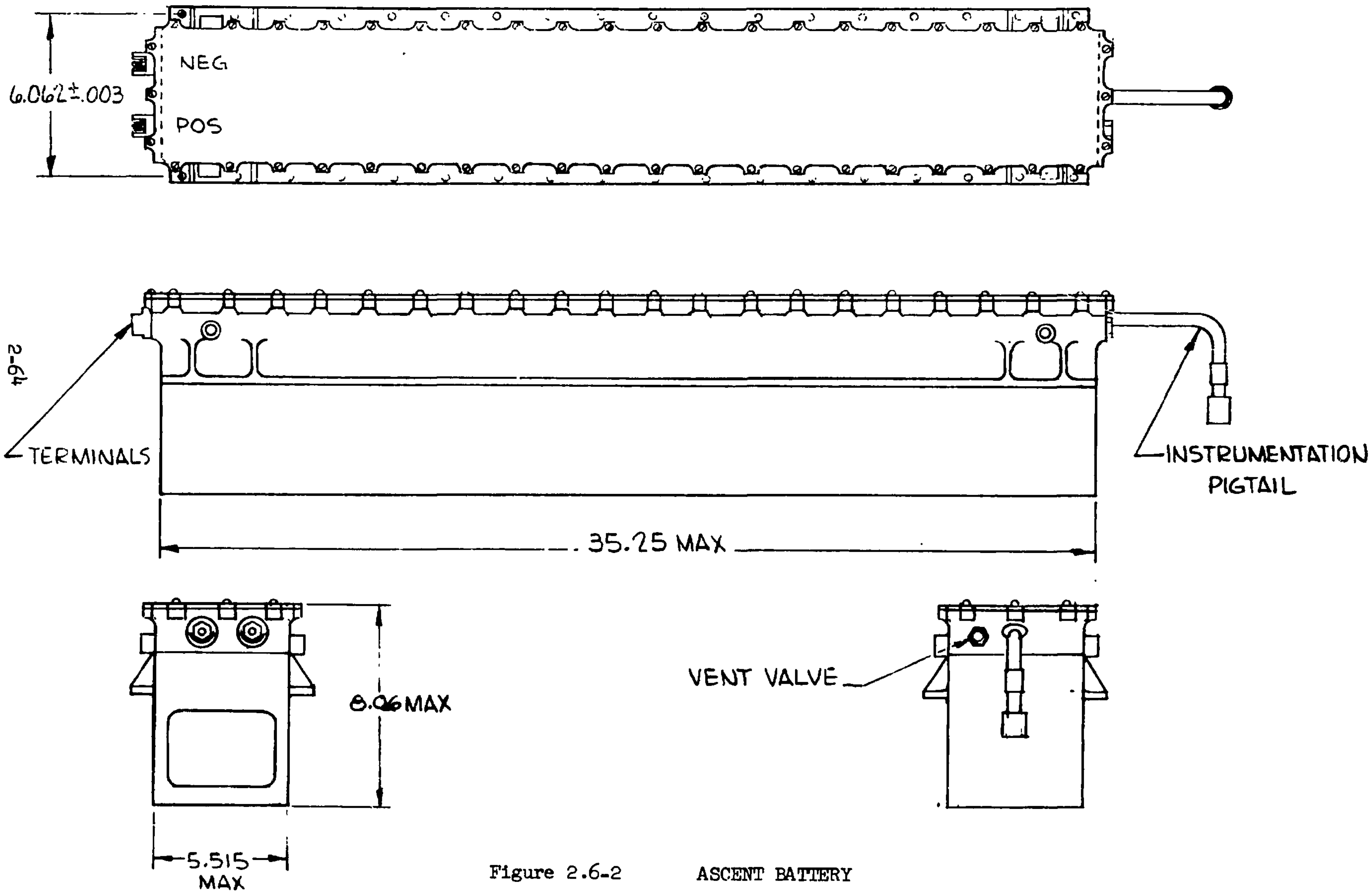


Figure 2.6-2 ASCENT BATTERY

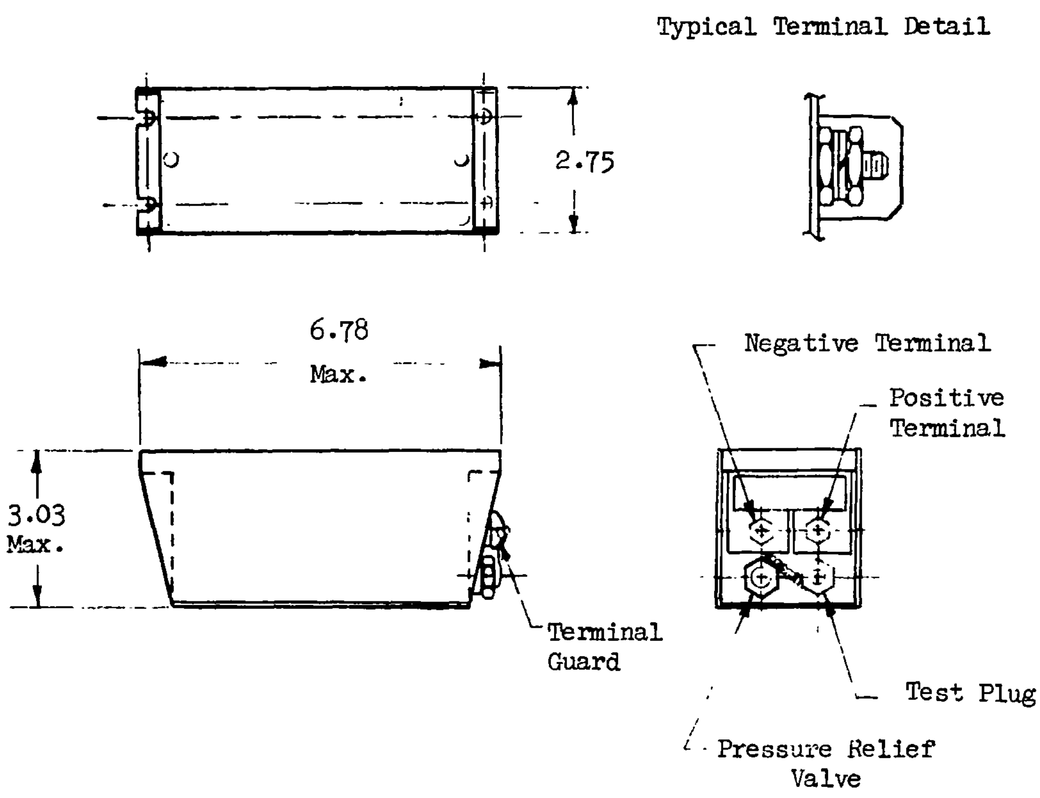


Figure 2.6-3 ED Battery

3. POTENTIAL ELECTRICAL ENERGY SOURCES

3.1 SUMMARY

A review has been made of the LM high pressure oxygen and propellant systems to determine if there are any components in these systems that could lead to a pressure vessel failure.

A review of the potential mechanical system causes of tank failures indicate that adequate design margins and redundancy exist. Section 2 presents a discussion of the conditions for which fewer than three mechanical failures can produce a propulsion system over pressure.

The analysis was not made for the time when the vehicle was powered down, namely from launch to LM activation. Therefore, the primary objective of this section is to evaluate the possibility of electrically induced system over pressurization from LM activation. The electrical energy sources which have been considered include pressure, temperature and quantity transducers, and engine and solenoid valves.

The investigation has shown that, with the exception of the Descent Engine pilot valve, none of the electrical components have ever experienced any failure where the medium that it monitors came in contact with the internal material of the subject components.

The failed Descent Engine pilot valve occurred at the vendor test facility on 7 June 1966. The analysis has shown that propellant leaked into the solenoid causing a short. Corrective actions have been taken by improving the sealing capability.

Squib valves were eliminated from consideration, since power is not supplied to the explosive initiator until the time of actuation. Once the valve is activated, power is no longer applied and the bridge wire internal to the cartridge is disintegrated by the explosion thereby breaking the connection. The RCS heaters have also been eliminated. Although these heaters are an intentional source of electrical energy input, they are sufficiently removed from the

3.1 cont'd

fuel and oxidizer systems (reference Figure 3.8-1) to be discounted as a source of pressure increase.

The components which are potential sources of electrical energy fall into three categories as shown in Table 3.1-1. The transducers are protected by 0.25 amp fuses and have a maximum power input of 7 watts.

The engine valves (APS, DPS and RCS) can produce up to 280 watts of heat input. However, since propellant is flowing during valve operation, the heat generated would be conducted to the thrust chamber and into space. The solenoid latch valves have a power input potential of 140 watts. However, the coils of these latching valves are operated momentarily, hence high power inputs are of short duration.

All of the LM circuit breakers have been certified by North American Rockwell, Inc. Report No. MC 454-0010. The circuit breakers were subjected to a qualification test program which included functional and environmental tests. Additionally, all the applicable fuse assemblies were subjected to a qualification program per LCQ 360-045, -046 and -047.

TABLE 3.1-1

SUMMARY OF ELECTRICAL ENERGY SOURCES

Category/ Component	Reference Paragraph	Max Electrical Power Input (Watts)	Remarks
Transducers			
(a) pressure	3.2, 3.3	1.6	The maximum electrical power input occurs in the sensor electronics, which is isolated from fluid system.
(b) temperature	3.4	0.0085	
(c) quantity (APS)	3.6	7	
(DPS)	3.5	8.2	Effective heat input reduced by flow conditions.
Engine valves	3.8, 3.9, 3.10	280	Adequate propellant flow conditions exist in all cases to remove heat.
Solenoid valves	3.7	140	Double failure required for continuous input. System temp. stabilizes at 100° F with negligible system pressure increase.

3.2 PRESSURE TRANSDUCER LSC 360-601 - XXX

The 360-601 transducer is an absolute pressure device which is used in the ECS, RCS, DPS and APS. The fluids being measured and the pressure range of the devices are listed in Table 3.2-1.

The pressure sensing device is a twisted Bourdon tube whose motion is proportional to pressure. A cross-sectional view of this transducer is shown in Figure 3.2-1. The wetted areas for normal operation and for a structural single-point failure of the Bourdon tube are also shown in Figure 3.2-1. The nonmetallic materials exposed to the pressure medium for normal and single-point failure cases are identified and discussed in Section 4.

As shown in Figure 3.2-2, power is supplied to this transducer through the signal sensor circuit breaker on panel 16 and a 1/4 amp fuse in the sensor power fuse assembly or ECS relay box. The maximum operating current is 10. ma at 28 VDC. For a single-point failure within the sensor electronics, the maximum power which could be drawn is 200 ma. However, a 147 -ohm (1/8 watt) resistor in the electronics would burn open under these conditions, terminating the current flow. The highest sustainable current for this device is 60 ma. At this current level, the limiting resistor mentioned above is dissipating 1/4 watt (twice rated power). This condition results in 1.6 watts of heat input to the adjacent pressure vessel.

The most critical installation of this transducer is in the descent oxygen line. This electrical energy source is not capable of inducing a tank failure.

This class of transducers has never incurred any applicable failure suggesting fluid breakthrough or excessive fluid heating due to electronic failure.

TABLE 3.2-1 APPLICATIONS OF PRESSURE TRANSDUCER LSC 360-601

SUB SYSTEM	DASH NUMBER	MEASUREMENT NUMBER	NOMENCLATURE	RANGE psia	FLUID
ECS	-203	GF 2741	Primary Pump Press	0-60	Water Glycol
	-203	2921	Red Pump Press	0-60	Water Glycol
	-207	3571	Cabin Press	0-10	Oxygen
	-201	3582	ASC Tank # 1 O_2 Press	0-1000	Oxygen
	-201	3583	ASC Tank # 2 O_2 Press	0-1000	Oxygen
	-209	3584	Desc. Tank O_2 Press	0-3000	Oxygen
	-205	3591	Upper Hatch Relief Press	0-25	Oxygen
	-205	3592	Fwd. Hatch Relief Press	0-25	Oxygen
	-203	4501	Des H_2O Press	0-60 (0-25 LM9)	Water
	-203	4500	H_2O Tank Press	0-60 (0-25 LM9)	Water
	-203	4502	H_2O Press LM-9	0-60 (0-25 LM9)	Water
	-203	4503	H_2O Press LM-9	0-60 (0-25 LM9)	Water
	-209	0584	Desc. GOX Pres.(LM-10) Desc. Tank H_2O Press	0-3000 0-60	Oxygen
RCS	-103	GR 1101	Sys. A He Tank Press	0-3500	Helium
	-103	1102	Sys. B He Tank Press	0-3500	Helium
	-105	1201	Sys. A He Manif. Pres	0-350	Helium
	-105	1202	Sys. B He Manif. Pres	0-350	Helium
	-105	2201	Sys. A Fuel Manif. Press	0-350	A-50
	-105	2202	Sys. B Fuel Manif. Press	0-350	A-50
	-105	3201	Sys. A Oxid Manif Press	0-350	N_2O_4
	-105	3202	Sys. B Oxid Manif Press	0-350	N_2O_4

Table 3.2-1 (Cont'd)

SUB SYSTEM	DASH NUMBER	MEASUREMENT NUMBER	NOMENCLATURE	RANGE psia	FLUID
DPS	-107	GQ 3018	He Reg. Out. Manif. Press	0-300	Helium
	-107	3025	He Reg. Out. Manif. Press	0-300	Helium
	-107	3501	Fuel Ullage Press	0-300	A-50, He
	-107	3611	Fuel Interface Press	0-300	A-50
	-107	4001	Oxid. Ullage Press	0-300	N_2O_4, He
	-107	4111	Oxid. Interface Press	0-300	N_2O_4
APS	-101	GP 0001	He Tank # 1 Press	0-4000	Helium
	-101	0002	He Tank # 2 Press	0-4000	Helium
	-107	0018	Reg. Outlet Press (fuel)	0-300	Helium
	-107	0025	Reg. Outlet Press (oxid)	0-300	Helium
	-107	0501	Fuel Ullage Press	0-300	Helium, A-50
	-107	1001	Oxid. Ullage Press	0-300	Helium, N_2O_4
	-101	0041	He Tank # 1 Press Redund.	0-4000	Helium
	-101	0042	He Tank # 2 Press Redund.	0-4000	Helium

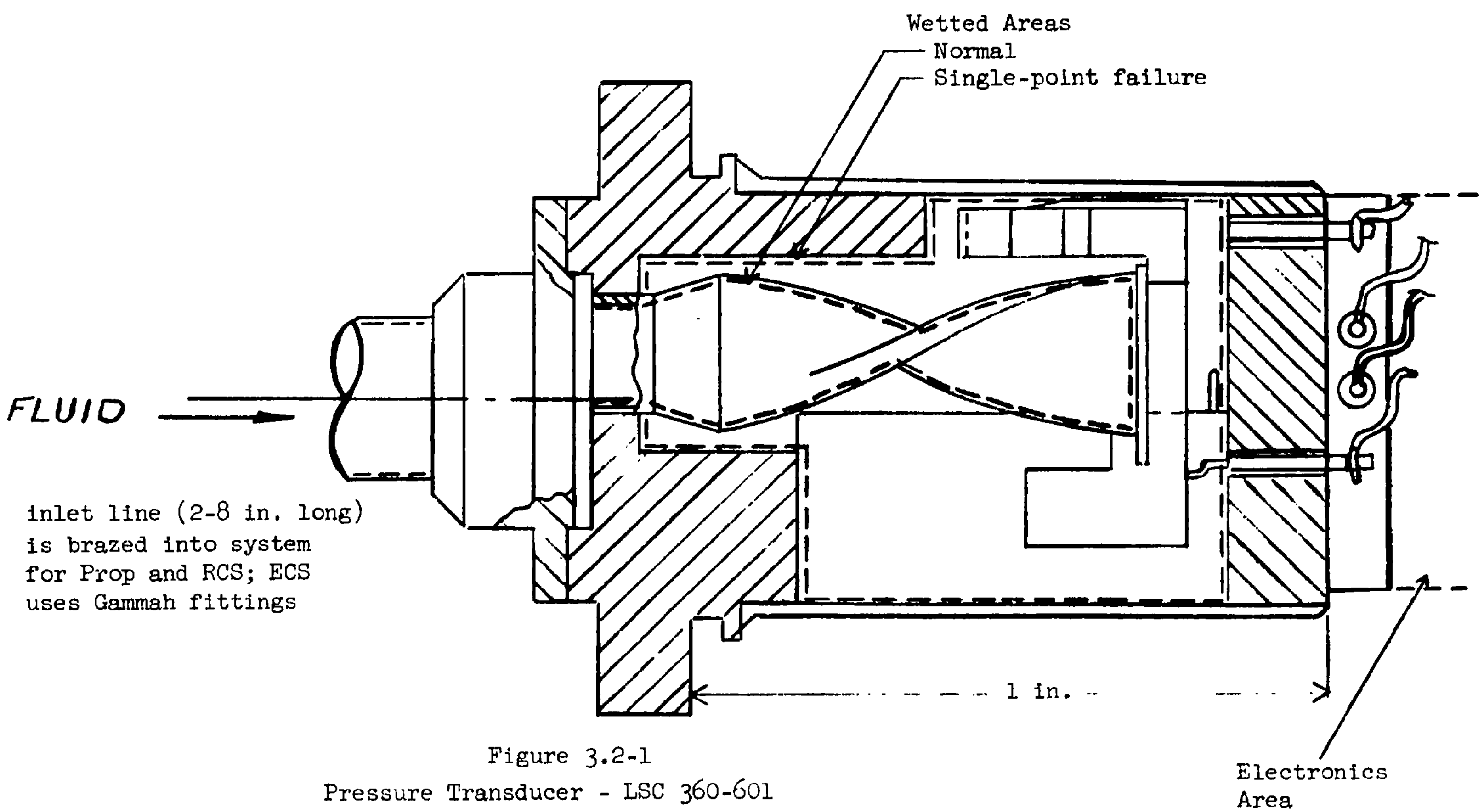


Figure 3.2-1
Pressure Transducer - LSC 360-601
(Sensor Area)

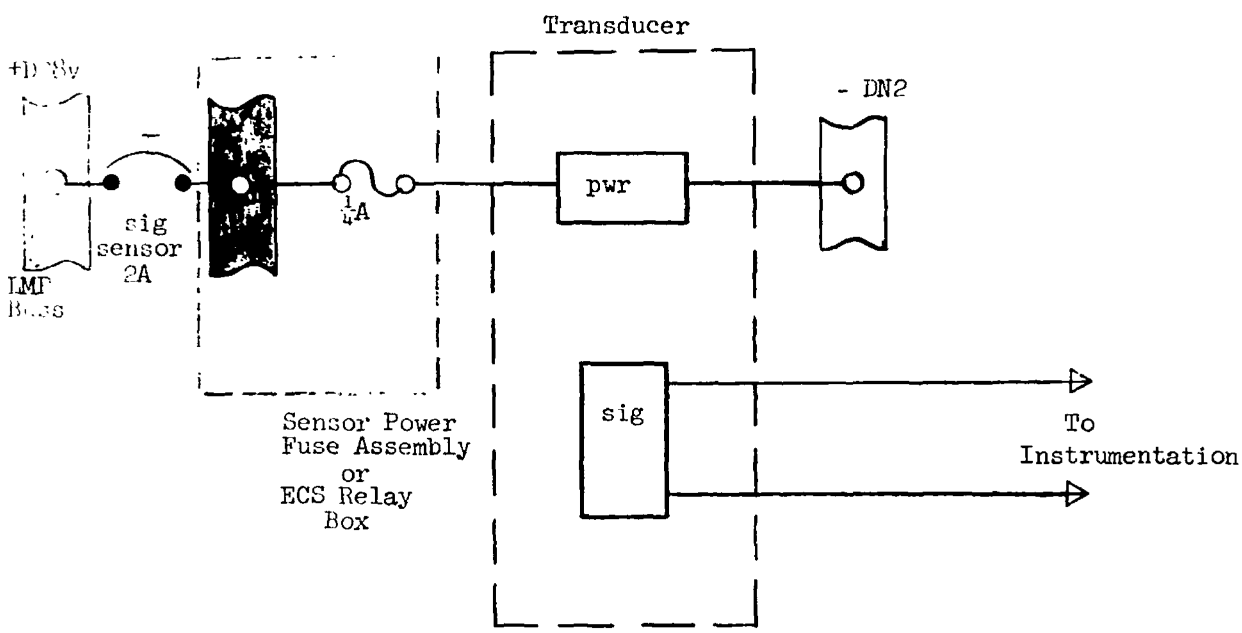


Figure 3.2-2
Pressure Transducer Schematic

3.3 PRESSURE TRANSDUCER LSC 360-624 - XXX

The 360-624 transducer is an absolute pressure device used in the ECS, APS, and DPS systems. The fluids being measured and the range of the device are listed in Table 3.3-1.

The pressure sensing devices are silicon strain gauges mounted on an integrally machined diaphragm. A cross-sectional view of this transducer is shown in Figure 3.3-1. The wetted areas for normal operation and for a structural single-point failure of the diaphragm are also indicated in Figure 3.3-1. The non-metallic materials exposed to the pressure medium for normal and single-point failure cases are identified and discussed in Section 4.

As shown in Figure 3.2-2, power is supplied to these transducers by the signal sensor circuit breaker on Panel 16 and a $\frac{1}{4}$-a fuse in the sensor power fuse assembly or ECS relay box. The maximum operating current is 10 ma at 28v. For a single-point failure within the sensor electronics, the maximum current that could be drawn is 0.15a. However, a 221-ohm (1/8 W) resistor in the electronics would burn open under these conditions, terminating the current flow. The highest sustainable current for this device is 46 ma. At this current level the limiting resistor mentioned above is dissipating $\frac{1}{4}$ watt (twice rated power). This condition results in 1.3 watts of heat input to the adjacent pressure vessel.

The most critical installation of this transducer is in the oxygen manifold. However since the power level is below that for the type-601 transducer (see Paragraph 3.2), no significant pressure rise can result from a failure of this transducer.

This class of transducers has never incurred any applicable failure suggesting fluid breakthrough or excessive fluid heating due to electronic failure.

TABLE 3.3-1

APPLICATIONS OF PRESSURE TRANSDUCER LSC 360-624

SUB SYSTEM	DASH NUMBER	MEASUREMENT NUMBER	NOMENCLATURE	RANGE psia	FLUID
ECS	-211	GF3589	O_2 Manifold Pressure	0-1400	Oxygen
DPS	-111	GQ3015	Start Tank Pressure	0-1750	Helium
APS	-1	GP1501	Fuel Isolation valve inlet pressure	0-250	A-50
APS	-1	GP1503	Oxidizer isolation valve inlet pressure	0-250	N_2O_4
APS	-3	GP2010	Thrust chamber pressure	0-100	A-50, N_2O_4

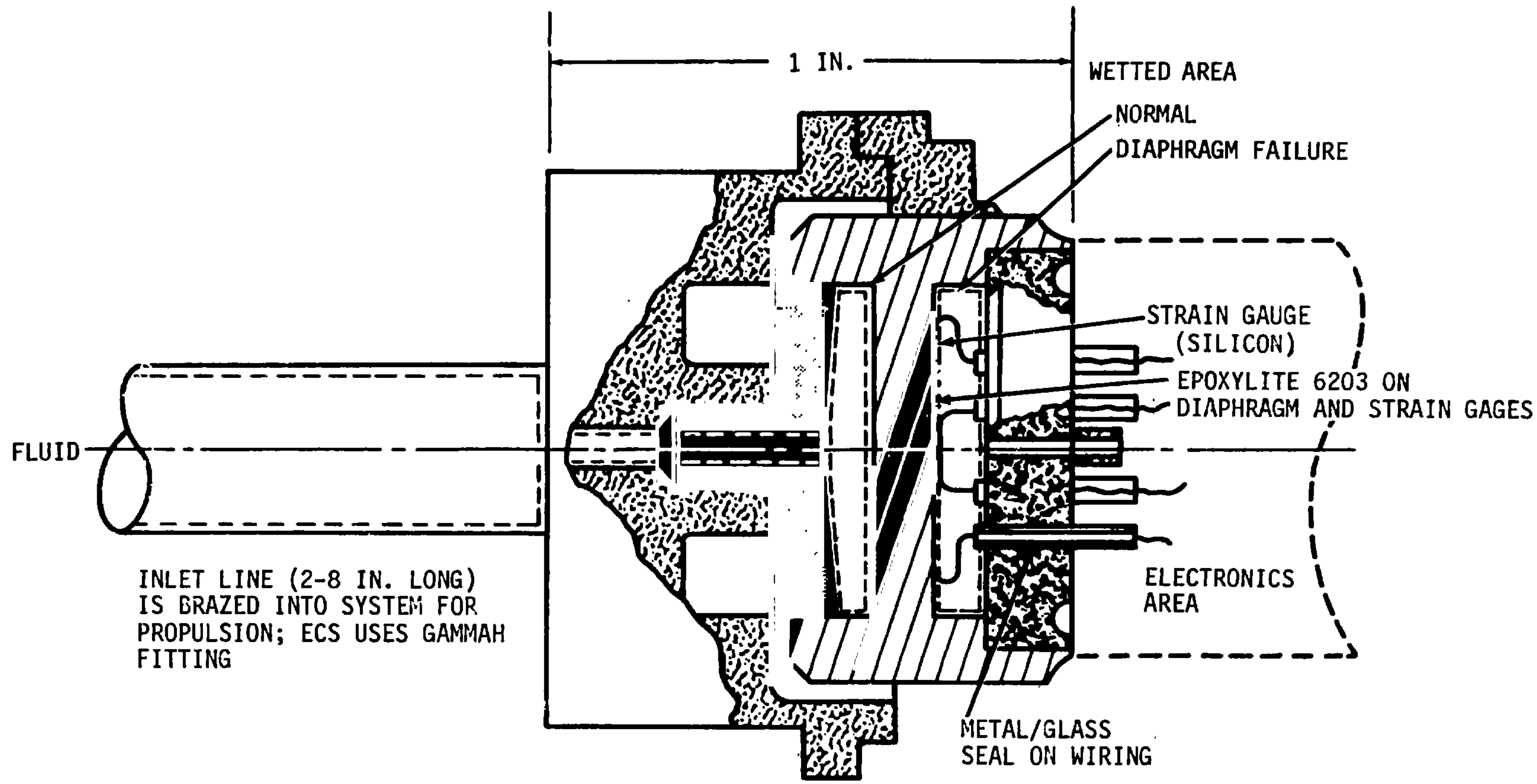


FIGURE 3.3-1. PRESSURE TRANSDUCER LSC 360-624
(SENSOR AREA)

3.4 TEMPERATURE TRANSDUCER LSC 360-605 - XXX

The 360-605 transducer is a resistance thermometer device used in the DPS and APS to monitor propellant temperature. The fluids being measured and the ranges of the device are listed in Table 3.4-1.

The resistance thermometer consists of a platinum wire sensing element enclosed in a cylindrical housing to allow sensing of the fluid temperature. A resistance-to-D C converter (503-2 module in SCEA) provides the analog voltage output proportional to the sensor resistance (nominally 1400 ohm at 32°F). A cross-sectional view, including wetted areas for normal and single-point failure conditions, is shown in Figure 3.4-1. The non-metallic materials exposed to the pressure medium for normal and single-point failure cases are identified and discussed in Section 4.

Power is supplied to this sensor from the above mentioned 503-2 SCEA module (reference Figure 3.4-2). Normal operating power is 0.5 ma at 8.5 VDC. The maximum power that can be delivered by the SCEA, as the result of circuit failure or propellant leakage, is .0085 watts.

This electrical energy input is incapable of producing a significant pressure rise in the fluid medium.

This class of transducers has never incurred any applicable failure suggesting fluid breakthrough or excessive heating due to electronic failure.

TABLE 3.4-1

APPLICATIONS OF TEMPERATURE TRANSDUCER LSC 360-605

SYSTEM	DASH NUMBER	MEASUREMENT NUMBER	MEASUREMENT NOMENCLATURE		RANGE	FLUID
DPS	-303	GQ 3718	Fuel tank # 1 Temp.		20-120	A-50
	"	3719	Fuel tank #2 Temp.	Note 1	20-120	A-50
	"	4218	Oxid. tank #1 Temp.		20-120	N_2O_4
	"	4219	Oxid. tank #2 Temp.		20-120	N_2O_4
APS	-303	GP 0718	Fuel tank Temp.		20-120	A-50
	-303	1218	Oxid. Tank Temp.		20-120	N_2O_4

NOTE 1: These immersion temperature measurements have been replaced by tank skin surface temperature measurements on LM-10 and subsequent.

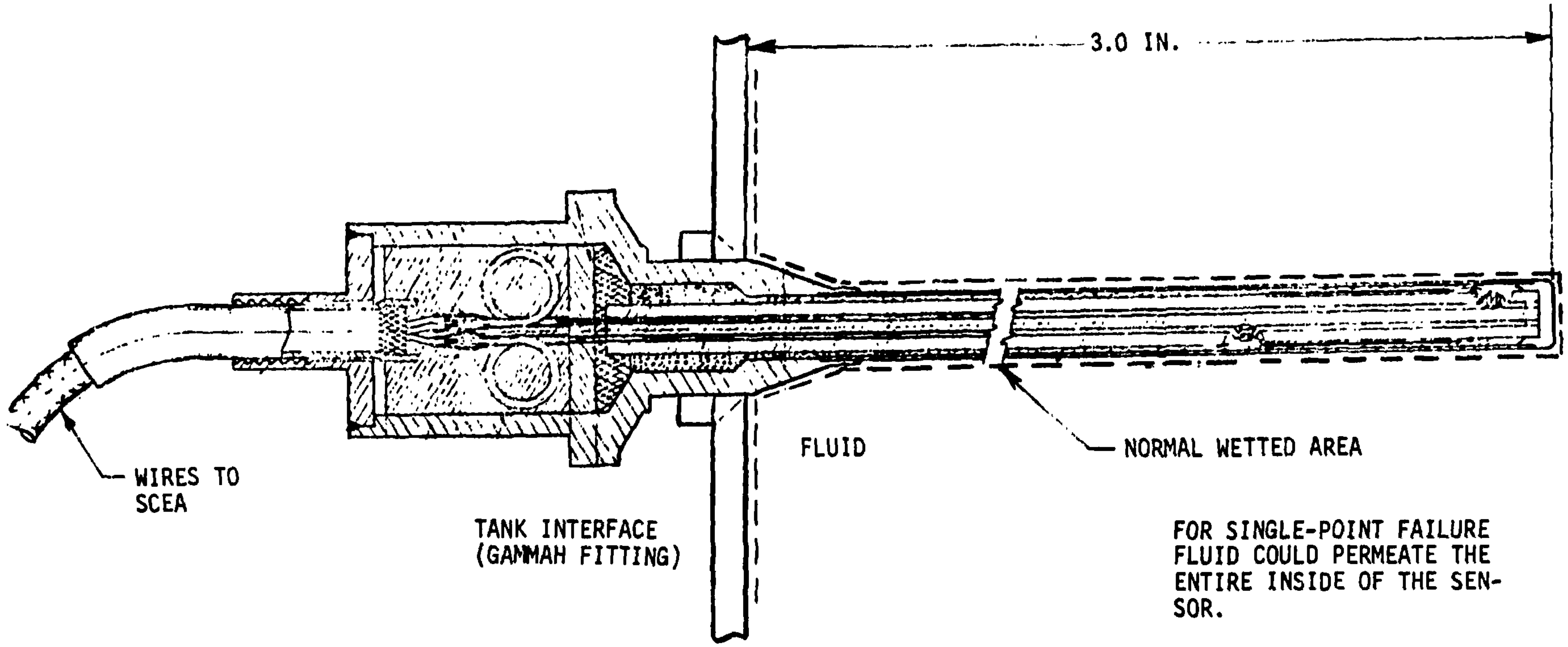


FIGURE 3.4.1. TEMPERATURE TRANSDUCER LSC 360-605 (IMMERSION TYPE)

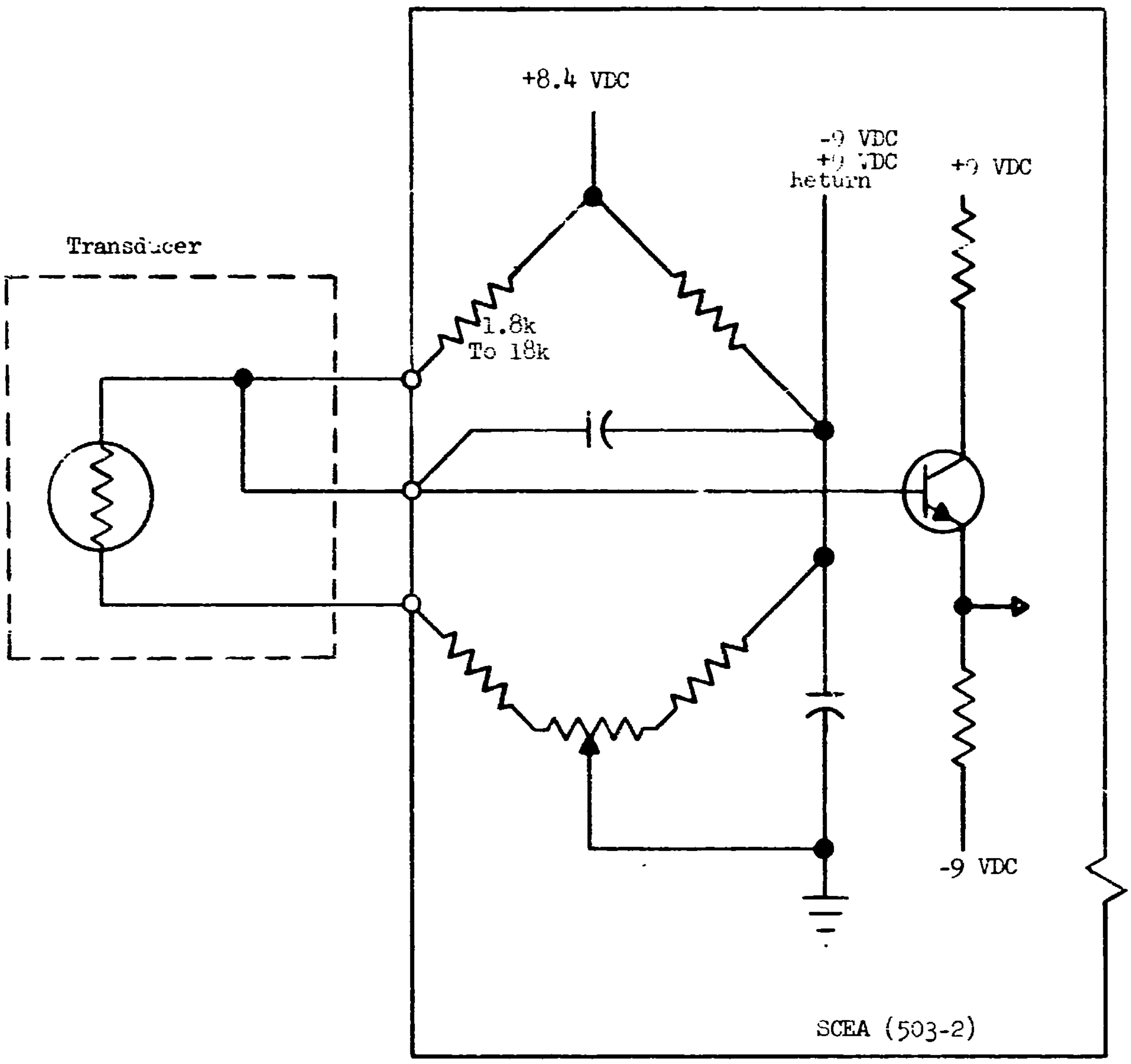


Figure 3.4-2
Temperature Transducer Schematic
(LSC 360-605)

3.5 PROPELLANT QUANTITY GAUGING SYSTEM LSC 370-00009-35

The DPS Propellant Quantity Gauging System (PQGS) consists of four probe assemblies, one in each propellant tank, and one control unit. The PQGS measures the conductance or capacitance of the fuel and oxidizer, respectively, and converts it to a quantity display and telemetry signal. In addition, each probe has a low-level sensor which actuates when 5.6% (9.375 inches) of propellant remains in the tank. The probes are bolted to the tank bottom and extend up to the diffuser flange at the top of the tank. A cross-sectional view of the probe assembly is shown in Figure 3.5-1. The fluid interfaces for normal and single-point failure conditions are shown in Figure 3.5-1. Materials in contact with the propellants are identified and discussed in Section 4.

A circuit diagram of the PQGS system is shown in Figure 3.5-2. Figure 3.5-3 is a simplified schematic of the sensor electronics. Since the control unit is located in Quad IV, removed from the tank locations, it has not been considered as an energy source. Normal operating current supplied to the sensor electronics, mounted at the tank bottom, is 54 ma at 20.5 volts (1.1 watts). Two failure types exist which could increase the energy input to the tank.

The first is an electrical failure in the sensor electronics that can increase the heat input. The control unit can deliver a maximum of 400 ma through a DC-to-DC converter to 2 probe assemblies. (The other 2 probes are powered by another 400 ma supply.) The maximum current drain for one probe is reduced by the converter efficiency and normal current to the second probe. Current draw in excess of 300 ma to one probe would cause the control unit overcurrent device to latch and stop the current flow. A sensor electronics failure resulting in current of up to but not exceeding 300 ma is improbable. A second failure would increase the current to 400 ma which is the value used in the following thermal analysis.

If a short circuit occurs (dissipating a maximum of 8.0 watts) within the 2.5 inch diameter potted electronics at the base of the tank (initially at $75^{\circ}F$), the transient thermal response of this volume will be $122^{\circ}F$ after 45 minutes and $179^{\circ}F$ after 2.0 hours of operation. The adjacent 1 cu. in. volume of propellant directly above the electronics case will reach $77^{\circ}F$ after 45 minutes and $93^{\circ}F$ after 2.0 hours. However, the PQGS is only on for $\sim$ 45 minutes and propellant

3.5 cont'd

is flowing out of the tank for the last 12 minutes.

Propellant leakage into the sensor electronics from a structural single-point failure could induce an electronic failure which would result in the same maximum sensor current. This failure would require a leak through the hermetic seal, leak through the silastic potting compound - RTV 20, decomposition of electronics capsule epoxy potting compound, and a circuit failure.

The second failure type is a failure of the sensor electrodes which could deliver electrical energy directly to the fluid in the sensor tube. Normal power dissipated in the fluid is 1 to 10 microwatts. A short circuit between any of the 4 electrodes, or from an electrode to ground, would increase the power dissipation in the electronics from 1.1 watts to about 1.6 watts. No power would be dissipated in the fluid since the electrode path through the propellant has essentially no resistance. In addition, the sensor electronics would stop current flow for a short circuit. The only failure mechanism which could increase fluid energy is a finite resistance path through the propellant (greater than 28 ohms for oxidizer, 0.15 ohms for fuel); no such failure mode could be postulated during this study. If this did occur, the power dissipation in the adjacent 1 cu. in. volume of fluid (initially at $75^{\circ}F$) would be .36 w.

A simplified transient thermal analysis was performed for both liquid and gas environments, assuming conduction to the surrounding fluid and aluminum tube. The following temperatures have been computed:

- 1 cu. in. of liquid: $107^{\circ}F$ after 45 minutes and $123^{\circ}F$ after 90 minutes
- 1 cu. in. vapor: (At 80 psia, the mixture will consist of 18% N_2O_4/ 82% He or 2.5% A-50/97.5% He)
  - N_2O_4: $230^{\circ}F$ after 3 minutes and $260^{\circ}F$ after 30 minutes
  - A-50: these temperatures will be lower because of the higher He content.

It can therefore be concluded that the DPS Propellant Quantity Gauging system cannot provide the electrical energy required to induce tank failure. In addition, the PQGS has never experienced a failure suggesting fluid breakthrough, excessive fluid heating due to electronics failure, or electrode short circuit.

The nonmetallic materials in the Propellant Quantity Gaging System (PQGS) located internal to the DPS fuel or oxidizer tanks and exposed to the propellants are Rulon A and Teflon.

The Rulon A material is a blend of Teflon TFE resin (Tetrafloroethylene) and ceramic strands manufactured by the Dixon Corp. They indicate that the material composition is proprietary however, heating for extended periods of time at temperature above 1000°F will drive off the Teflon leaving a white powder ash of the ceramic. Analysis of Rulon A here at GAC have indicated the major constituents of this ash to be aluminum magnesium silicate. The ceramic filler is added to the Teflon to increase stiffness and prevent creep and cold flow of the material. Compatibility of the material with fuel and oxidizer at ambient temperature for 60 days was demonstrated in Allison Report BC. 0365-045 dated 5-9-66 "Evaluation of Rulon Covered Teflon Bumpers for LEM Descent Stage Propellant Tank Antislosh Baffle." There is 0.26 pounds of Rulon A in the PQGS exposed to the propellants.

There is 0.055 pounds of Teflon in the PQGS exposed to the propellants. This Teflon is used as tubing, sheeting and a diffusion bonded coating (green) containing a chromium oxide to give it the green color. The Teflon used is primarily a TFE and FEP resin (Florinated ethylene-propylene). Numerous reports demonstrate the compatibility of TFE and FEP with propellants at ambient temperature.

The PQGS electrodes penetrate the pressurized area through a glass to metal seal. External to this seal (no propellant exposure) the electrical leads are potted in an approximately $1\frac{1}{2}$ inch long column of RTV-20 silicone rubber. There is .017 pounds of this silicone rubber.

The electrical leads then terminate in an electronics package containing numerous nonmetallics such as printed circuit boards, etc. with the primary nonmetallic being an epoxy, Stycase 1090. There is 0.3 pounds of Stycast 1090 located in the electronics package. The volume of the 6061 aluminum electronics package housing the RTV-20 and Stycase 1090 is 14 cubic inches.

No information is currently available on the flammability of Rulon A, Teflon, RTV-20 or Stycase 1090 in N_2O_2 or A-50. Recent tests conducted at Atlantic Research Corp. indicate that fuel vapors can be ignited as a monopropellant with an electrical spark at approximately 450°F and the fuel liquid can be ignited at approximately 550°F. Teflon exposed in the fuel liquid and vapors during these tests did not burn. Tests conducted in air or oxygen have indicated the autoignition temperature for epoxys such as Stycast 1090 and for silicone rubbers such as RTV-20 to be over 600°F. These temperatures would be expected to be at least as high in N_2O_4, assuming N_2O_4 could support combustion.

An analysis has been made for the pressure rise in the propellant tanks or the electronic package housing, assuming that these quantities of the above nonmetallic materials have burned.

Assumed Propellant Tank Ullast Vol. 0.94 ft.^{3}

Expected	P =	79 psi for Rulon A plus Teflon
		16 psi for RTV-20
		175 psi for Stycast 1090

Assumed Electronics Package Vol. 14 in.^{3}

Expected	P =	1860 psi for RTV-20
		20300 psi for Stycast 1090

From this analysis of delta pressure rise it can be seen that combustion of the nonmetallics could cause a tank pressure rise to the 260-275 psi pressure relief limit and vent. However, combustion and pressurization within the electronics package would cause that unit to be overpressurized resulting in seal leakage or case failure.

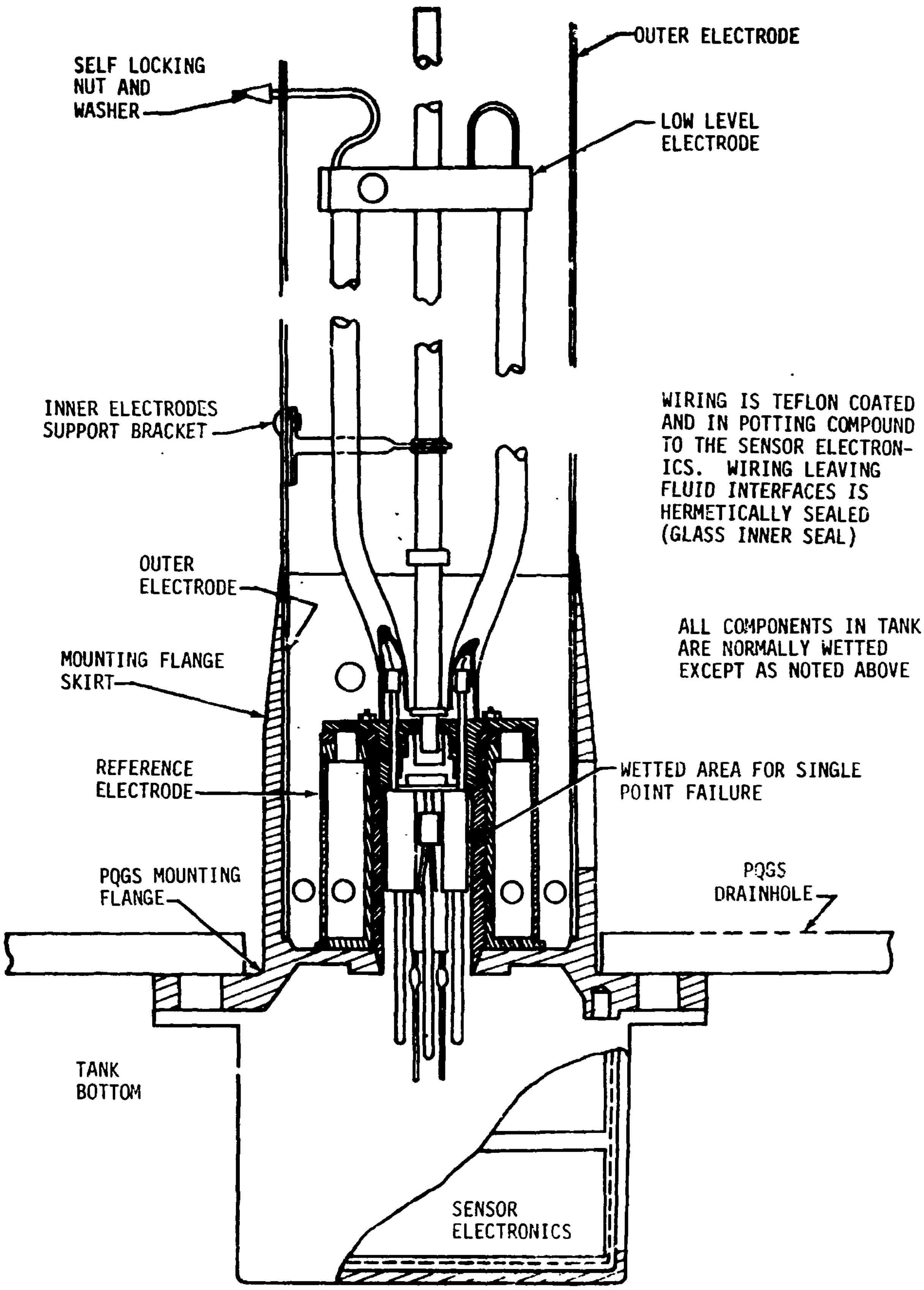


FIGURE 3.5-1. PQGS SENSOR.

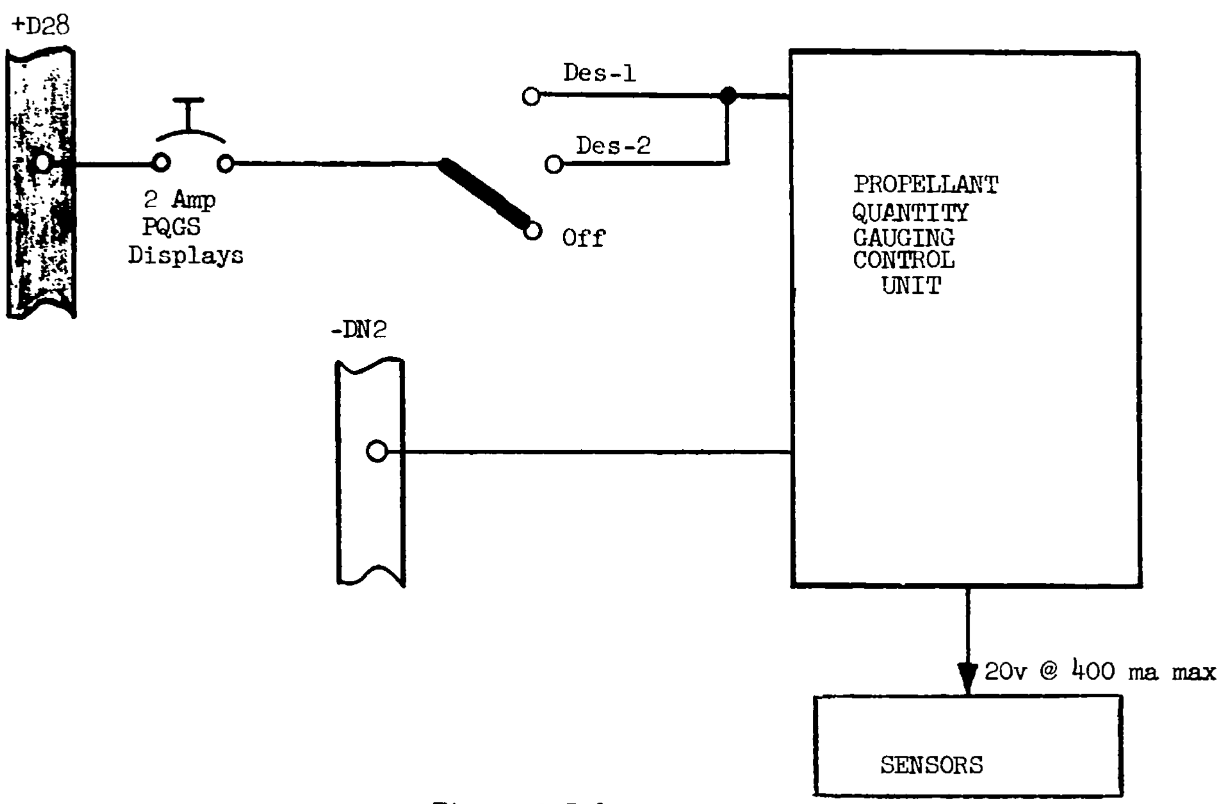


Figure 3.5-2

PQGS System Schematic

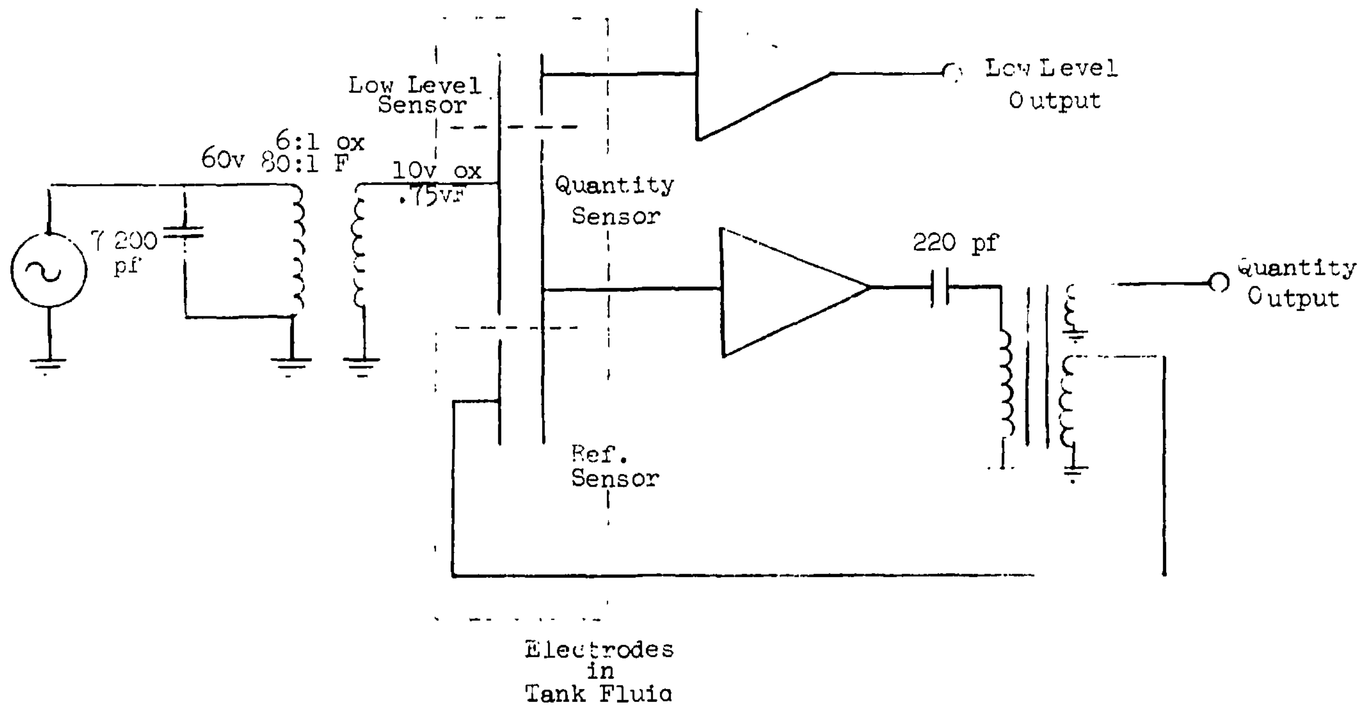


Figure 3.5-3
PQGS Sensor Schematic

3.6 PROPELLANT LEVEL DETECTOR LSC 270-801

The low-level detector for the ascent propellant tanks consists of a probe assembly extending into the tanks which contain magnetic coils and their associated circuitry. Figure 3.6-1 is a cross-sectional view of the detector showing fluid interfaces for normal and single-point failure conditions. The non-metallic materials exposed to the fluid medium for these conditions are identified and discussed in Section 4.

The propellant level detector is powered from the sensor power fuse assembly as shown in Figure 3.6-2. The normal power requirements are 8 ma at 28v (.22 watts). Two failure modes exist which would result in higher electrical energy inputs.

Failure of a capacitor in the electronics could result in 28 v being applied either directly across a 1K resistor or a forward biased diode. In the first case, the power dissipation increases to 0.9 watts, which would be transmitted to the tank and its contents. For the second case. the current would rapidly exceed the 250 ma rating of the fuse and the current flow would cease when the fuse opens.

A weld failure of the sensor case would allow N_2O_4 to enter the sensor tube, and react with the potting. Since this could result in numerous circuit failure modes, the worst case is assumed to be the maximum current that can be drawn through the fuse (250 ma). This increases the electrical heat input to 7 watts.

If a short circuit dissipating a maximum of 7 watts occurs within the potted electronics in the probe (initially at 75^{o}F), the average temperature of the probe will be 170^{o}F after 45 minutes and 175^{o}F after 4 hours of operation. The thermal response of the adjacent $\frac{1}{2}$ in. thick cylinder of propellant surrounding the probe will be 80^{o}F after 45 minutes and 82^{o}F after 4 hours of operation.

It can therefore be concluded that the Propellant Level Detector cannot provide the electrical energy required to induce tank failure.

The Propellant Level Detector has never experienced any applicable failure suggesting fluid breakthrough or excessive fluid heating due to electronic failure.

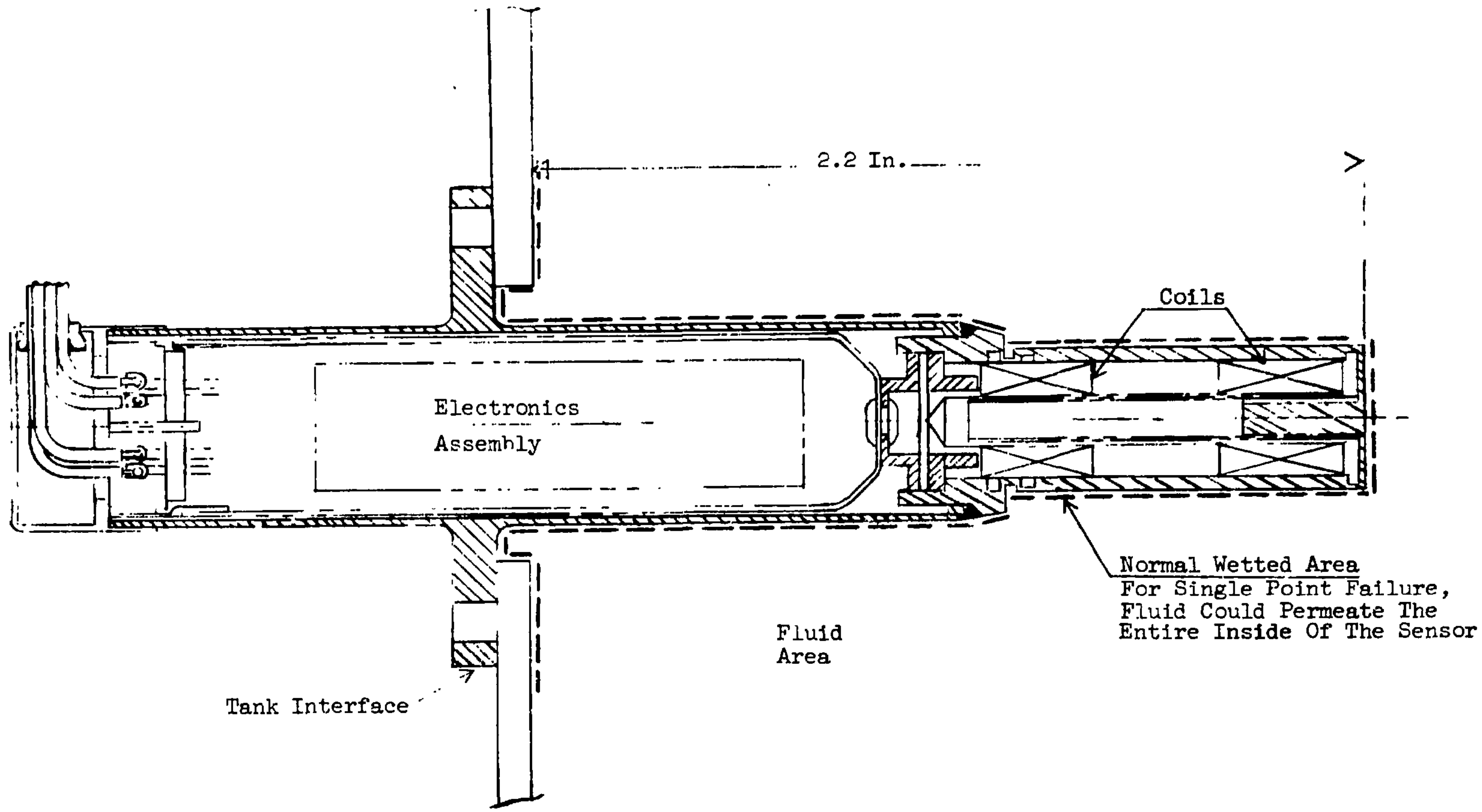


Figure 3.6-1
Propellant Level Detector

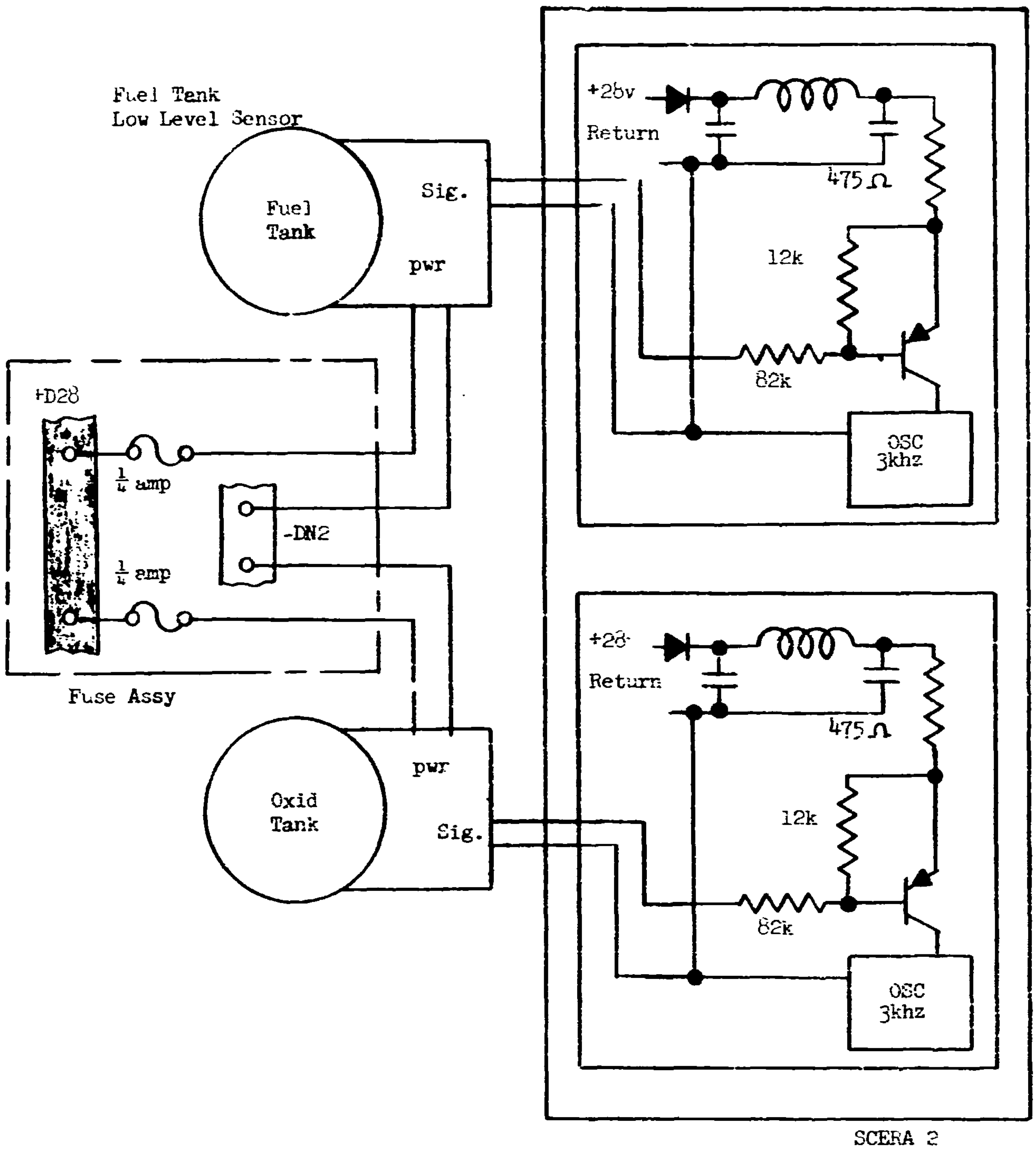


Figure 3.6-2
Propellant Level Detector Schematic

3.7 SOLENOID VALVE LSC 310-403

This latching solenoid valve is used in the RCS as the Main Shutoff (4), crossfeed (2), quad isolation (16) and ascent feed (8) Valves; it is also used in the DPS for lunar dump (2). (Note: The RCS quad isolations valves are deleted on LM-10 and subsequent.) The locations of these valves are shown in Figures 2.1-2 and 2.1-6. The wetted areas for normal and single point failure conditions are shown in the cross-sectional view in Figure 3.7-1. The materials exposed to the pressure medium for normal and single-point failure conditions are identified and discussed in Section 4.

The electrical configuration for all installations is the same, and is shown in Fig. 3.7-2. Power consumption and circuit breaker protection for each valve installation under normal conditions are summarized in Table 3.7-1.

The maximum electrical energy input to the fluid system would result from a partial coil short causing current to be drawn up to the circuit breaker protection limit. This condition could result in electrical energy inputs up to 140 watts. A similar failure could be induced in the coils, if the propellant were to leak past the structural interface and dissolve the coil potting.

Propellant flows through the valve cavity and is separated from both solenoid coils by a stainless steel plate welded into the valve structure. Normal operating pressure is 180 psi at 70°F.

The probability of the propellant penetrating the stainless steel shell separating the propellant from the electrical coil is low. However, should this condition occur, the propellant would dissolve the potting compound surrounding the coil.

The pressure generated by the reaction and the pressure rise resulting from increased current can relieve into the surrounding area through the hole in the valve used to bring the electrical leads to the coil.

3.7 cont'd

Pressure can also relieve through the propellant lines to the tank ullage volume. In no case could a significant pressure rise occur in the tanks as a result of this failure. In addition, since power is supplied to the valve only when it changes state, even the worst case input of 140 watts could only exist for one or two seconds. The longest steady state energy input resulting from a single failure is 50 watts due to a failed "on" solenoid coil.

Test data indicate that in the flight configuration (fluid in the cavity) the valve temperature would stabilize at 400-450°F. If a main shutoff valve fails in this manner, the tank temperature would increase to, and stabilize at, 100°F in about 50 hours. This is well below the energy level required to damage the system.

Therefore, solenoid valve failures of any kind cannot contribute significantly to a system pressure increase.

This solenoid valve has never experienced any applicable failure suggesting fluid breakthrough or excessive fluid heating due to solenoid coil defect.

TABLE 3.7-1

SOLENOID VALVE ELECTRICAL CONFIGURATIONS

APPLICATION	CIRCUIT BREAKER	RATING	VALVES/ CB	COMMENTS
RCS Main Shutoff	Sys A (B) Main SOV	5A	2	
RCS Quad Isolation	Sys A (B) Isol Vlv.	5A	8	Removed from LM-10 & Sub
RCS Ascent Feed	Sys A (B) ASC Feed	5A	4	
RCS Crossfeed	Crsfd.	5A	2	
DPS Lunar Dump	Des. He Reg/Vent	5A	2	

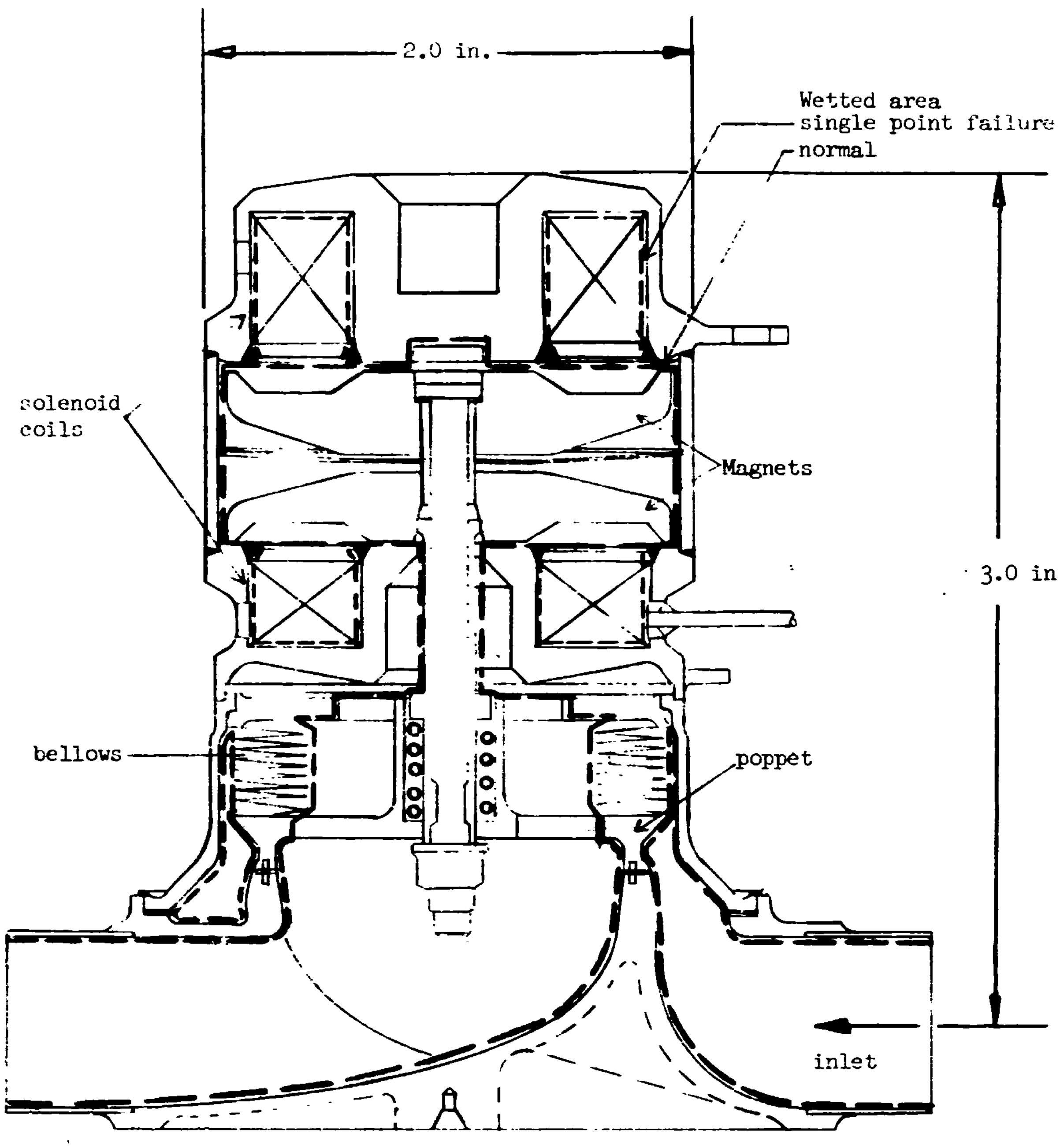


Figure 3.7-1
Solenoid Latch Valve

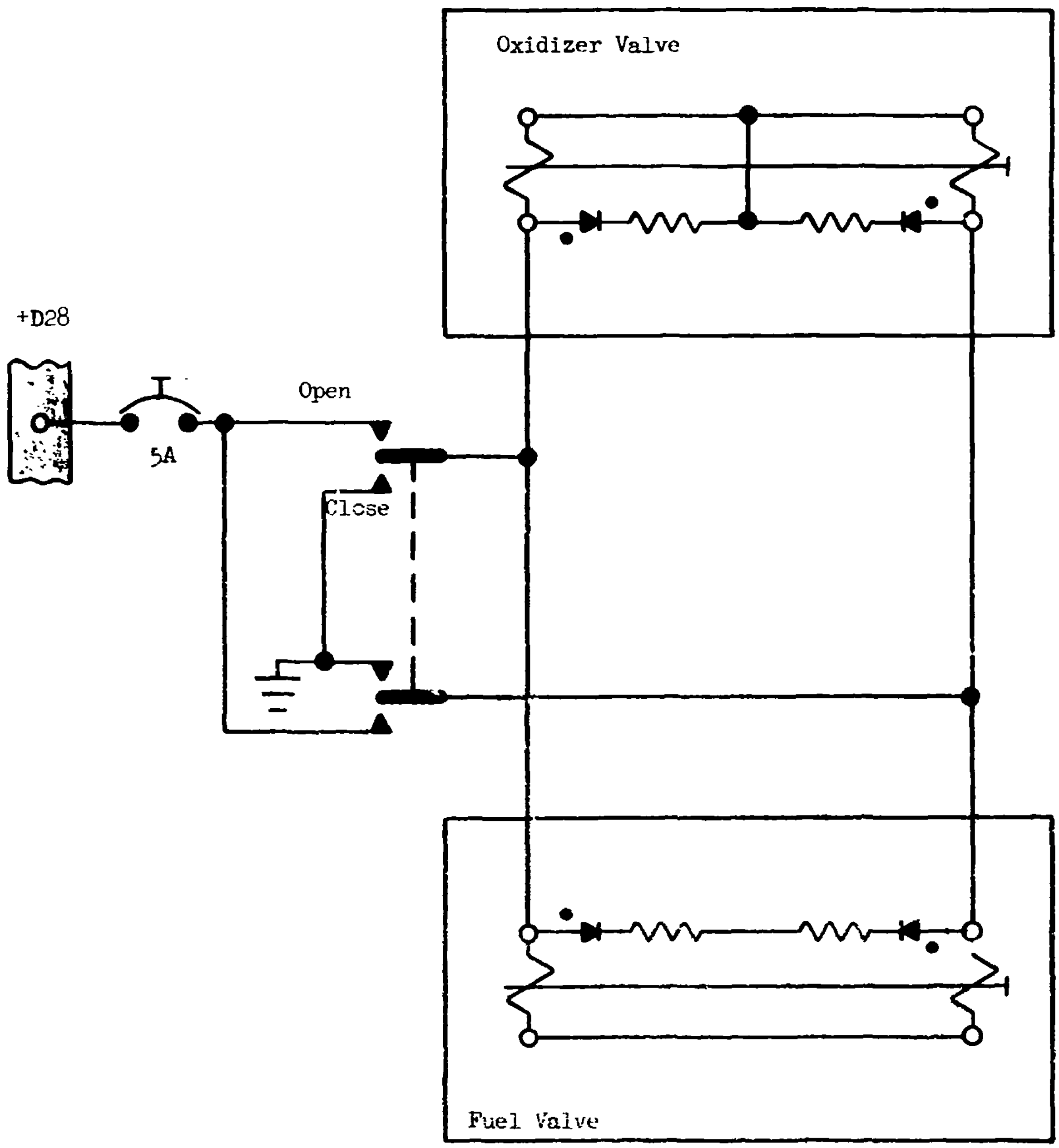


Figure 3.7-2

Solenoid Valve Schematic
(same for all applications)

3.8 RCS INJECTOR VALVE LSC 310-130

The RCS Injector Valves control the fuel and oxidizer flow in the RCS engines. There are 2 valves per engine, 32 total per vehicle. Each valve contains 2 coils; the primary coil for normal operation and the secondary coil for backup operation. A cross-sectional diagram of the injector valve, including the wetted area for normal and single-point failure conditions, is shown in Figure 3.8-1. Materials exposed to the propellant for these conditions are identified and discussed in Section 4.

Power is supplied to the primary valve coils from the eight Thrust Chamber Assembly quad circuit breakers through the jet drivers in the ATCA. The secondary coils are powered from the Attitude Direct Control circuit breaker on Panel 11 through the Attitude Controller Assembly hardover switches and the + X Translation push button (for downward firing jets only). Also, when mode control switches (one per axis) are in direct, the secondary coils are powered through the pulse/direct switches of the ACA. These circuit configurations are illustrated in Figures 3.8-2 and 3.8-3.

Normal injector operating current is 2 amps at 28 volts. As in the case of the solenoid valve, two failure modes exist which could result in heat input; partial coil short circuit or potting corrosion resulting in heat buildup and coil damage. However, when the injector valves operate, they provide a fluid path to the vacuum of space, hence electrically induced pressure buildup in the injector valve is impossible. The valve will operate for any short circuit up to the circuit breaker current limit, since the magnetic field is approximately constant for any partial coil short circuit (i.e. half the turns yields twice the current, hence the magnetic field is constant). If the engine fails to fire, the RCS caution and warning will advise the crew to open the circuit breaker. Therefore, the RCS injector valves cannot be considered a significant source of energy input.

The RCS injector valves have never experienced any applicable failure suggesting fluid breakthrough or excessive fluid heating due to valve coil defects.

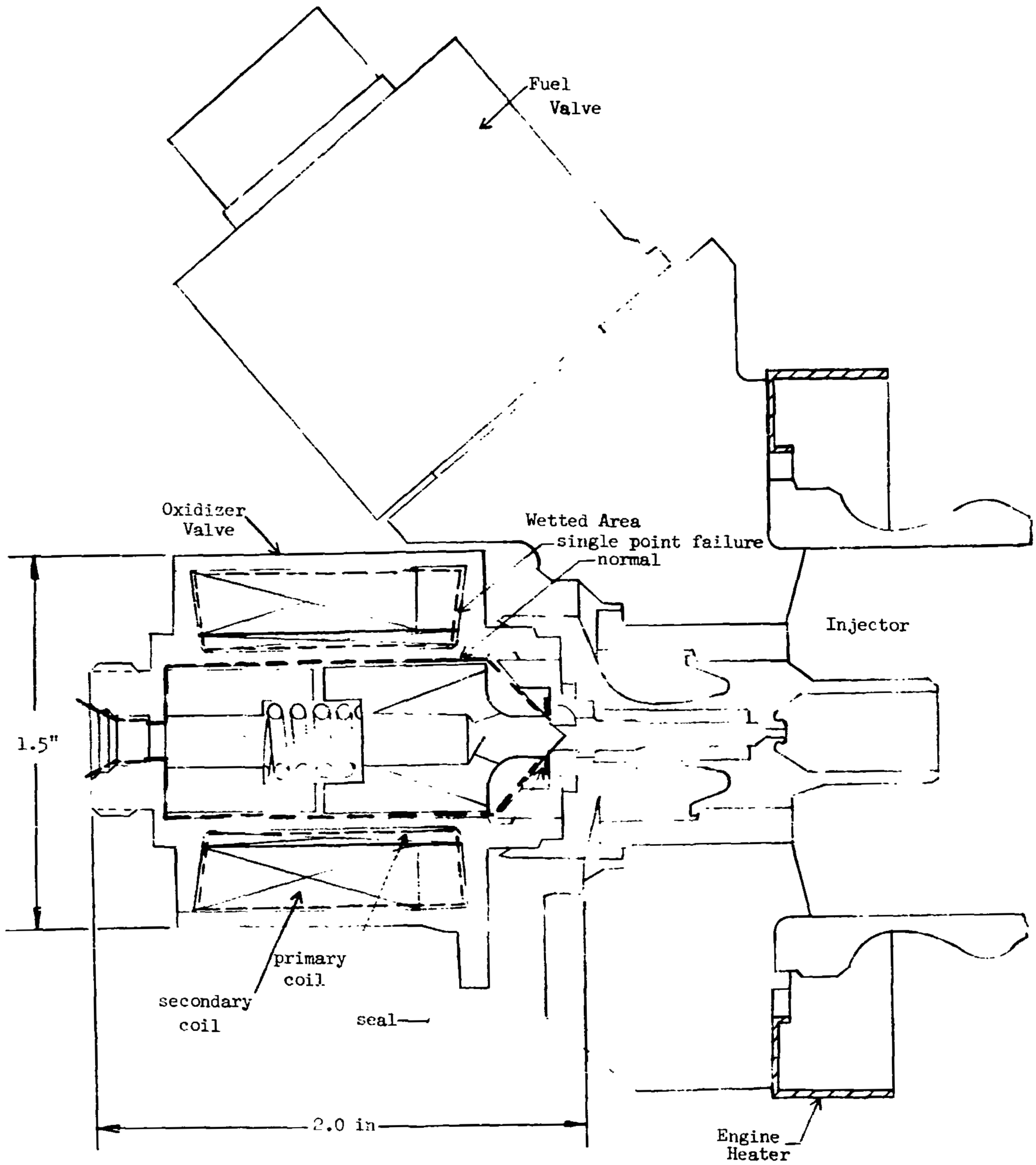


Figure 3.8-1
RCS Injection Valve

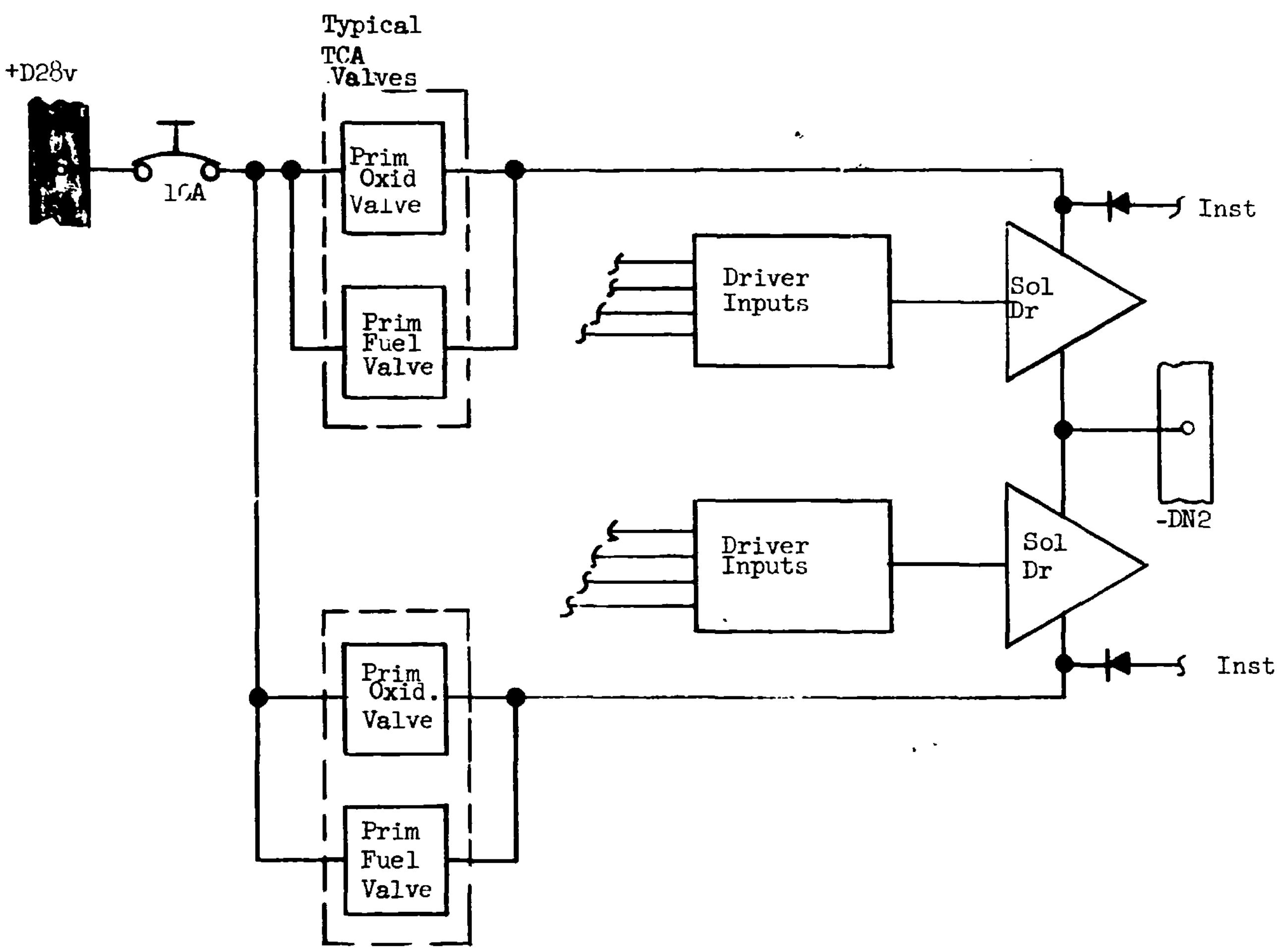


Figure 3.8-2

RCS Injection Value Schematic
(primary coils)

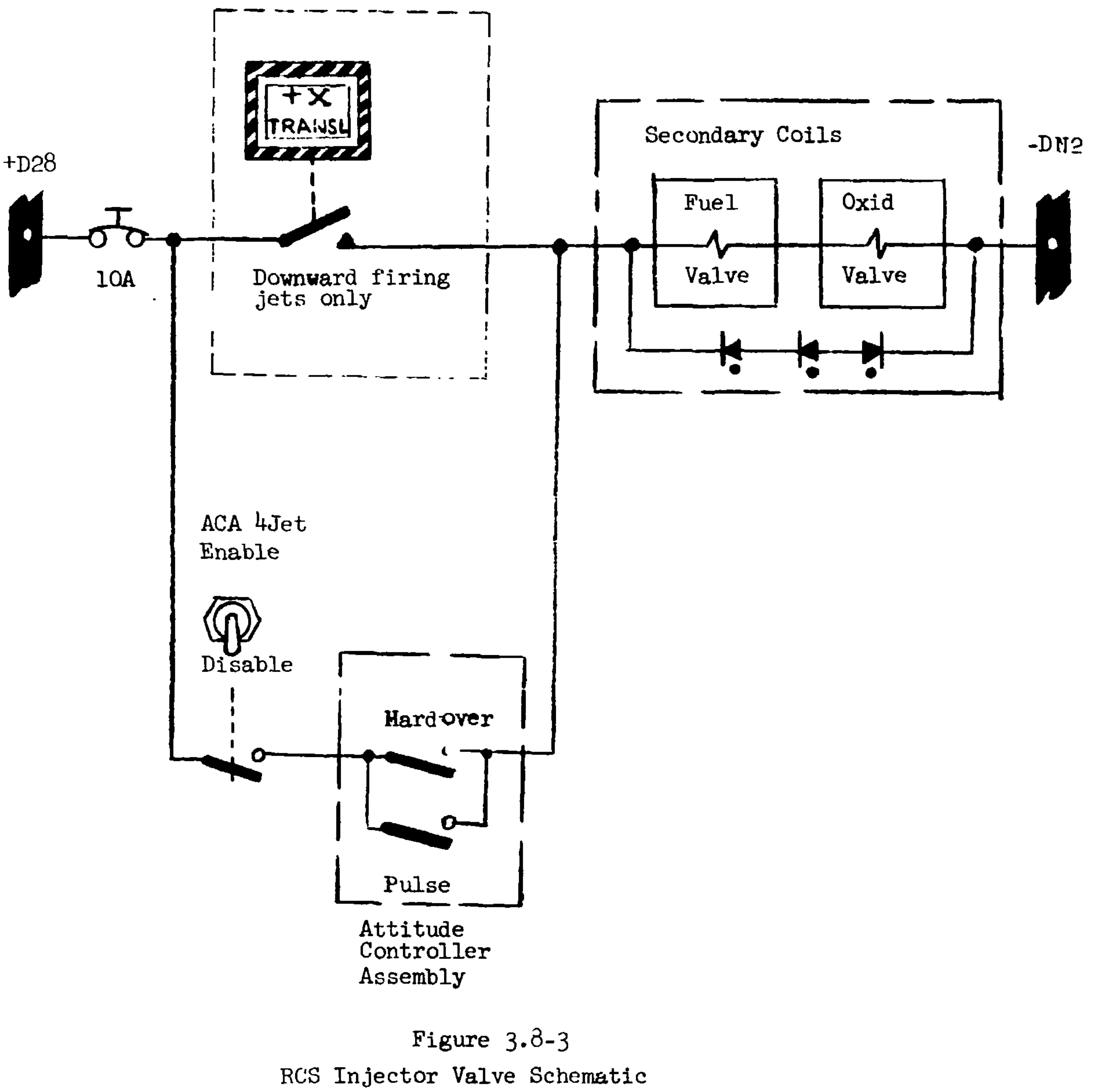


Figure 3.8-3
RCS Injector Valve Schematic
(secondary coils)

3.9 ENGINE PRE-VALVES (DPS & APS)

The pre-valves in the main propulsion engines are used to isolate the fuel from the solenoid pilot valves. These valves are the same for the ascent and descent engines. A cross-sectional view of this component, including fluid interfaces for normal and single-point failure conditions, is shown in Figure 3.9-1. Materials exposed to the fluid medium for these conditions are identified and discussed in Section 4.

Power is supplied to the APS pre-valves from the CDR and LMP Ascent Engine Latching Device (AELD) circuit breakers through series/parallel relay contacts as shown in Figure 3.9-2. The pre-valves are opened for an engine-on command, along with the pilot valves. Normal operating current is 1 amp. Two failure modes exist which could cause an increase in electrical energy input. A partial coil short could result in current drawn up to the circuit breaker protection limit of 4.5 amps (assuming other valves drawing normal current). A leak into the coil area could induce a similar failure by dissolving the potting and causing coil shorts. For either of these failures of the APS pre-valves, the maximum heat input is 125 watts. Since the valves are only energized when the engine is firing, any local heating will be conducted away by the propellant flow.

The DPS pre-valves are powered from the DECA power and Descent Engine Override circuit breakers through normally open relay contacts. This configuration is shown in Figure 3.9-3. The pre-valve is actuated by the engine arm switch in the descent position. The same failure modes as on the APS exist for this valve. However, the DPS pre-valve is not operated simultaneously with the engine valves. In flight, the engine is armed (pre-valves open) 5-10 seconds prior to ignition. This condition would not allow appreciable heat input prior to conducting the energy away with the flowing propellants. Therefore, such a condition is not capable of providing any appreciable pressure rise to the related system.

The engine pre-valves have never incurred any applicable failure suggesting fluid breakthrough or excessive heating due to electronics failure.

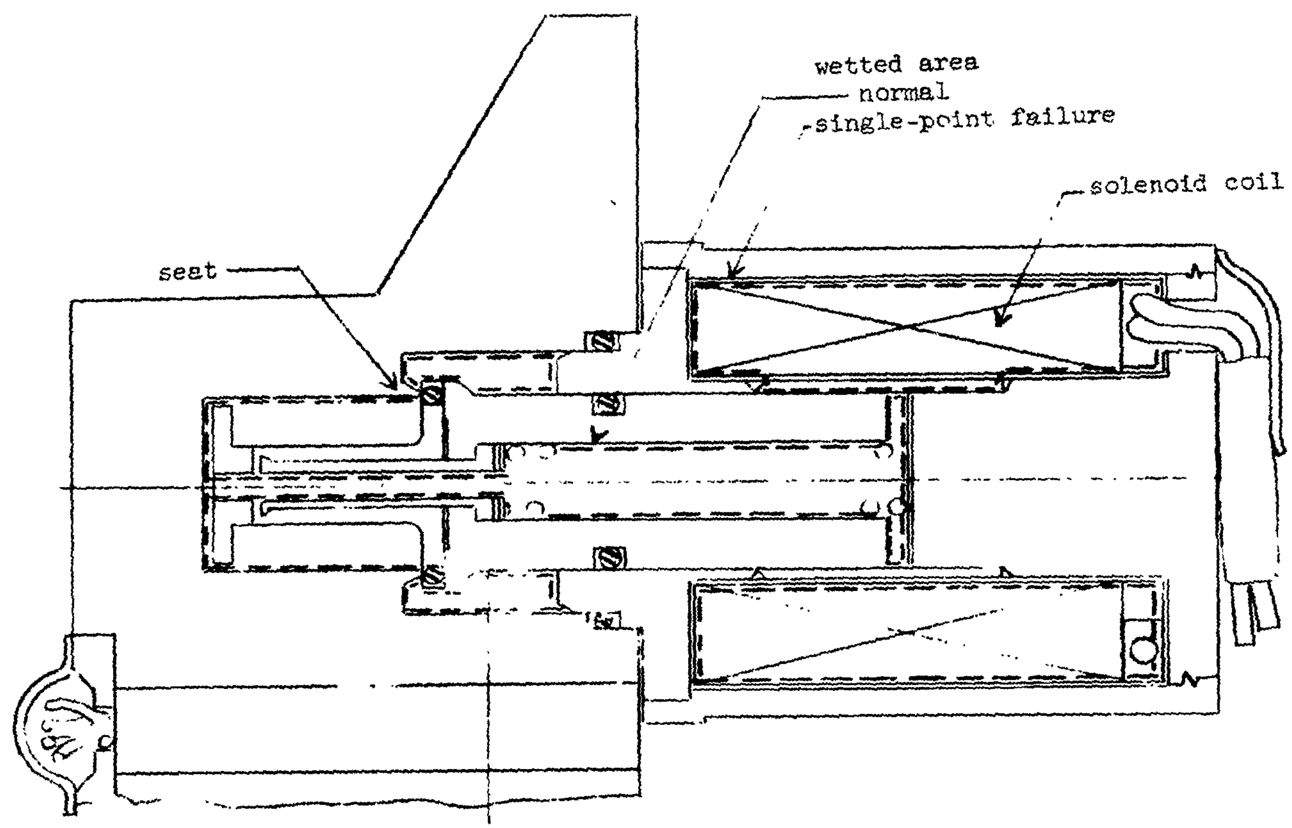


Figure 3.9-1
Solenoid Pre Valves
(APS & DPS)

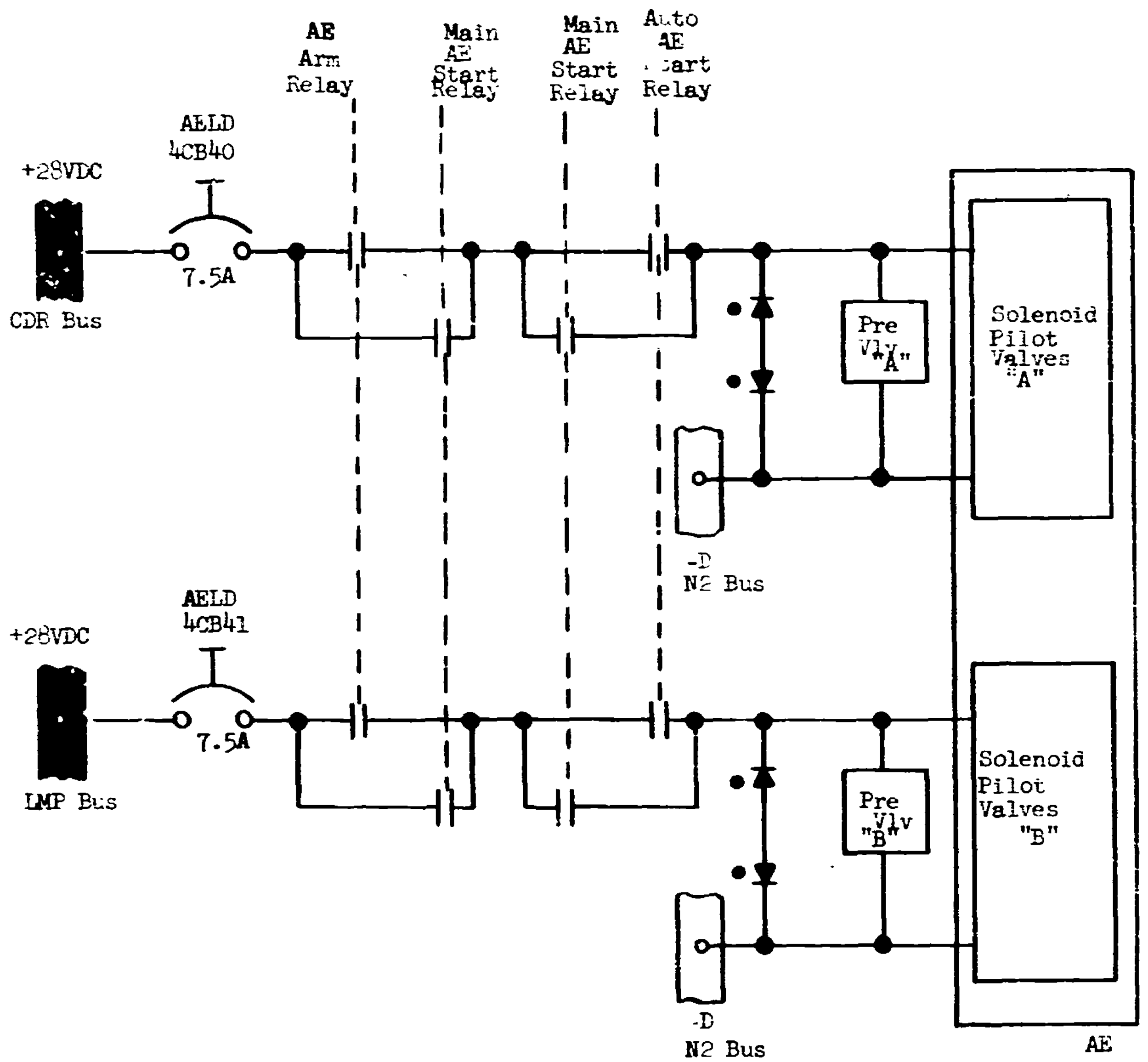


Figure 3.9-2
APS Pre-Valve and Solenoid Pilot Valve
Schematic

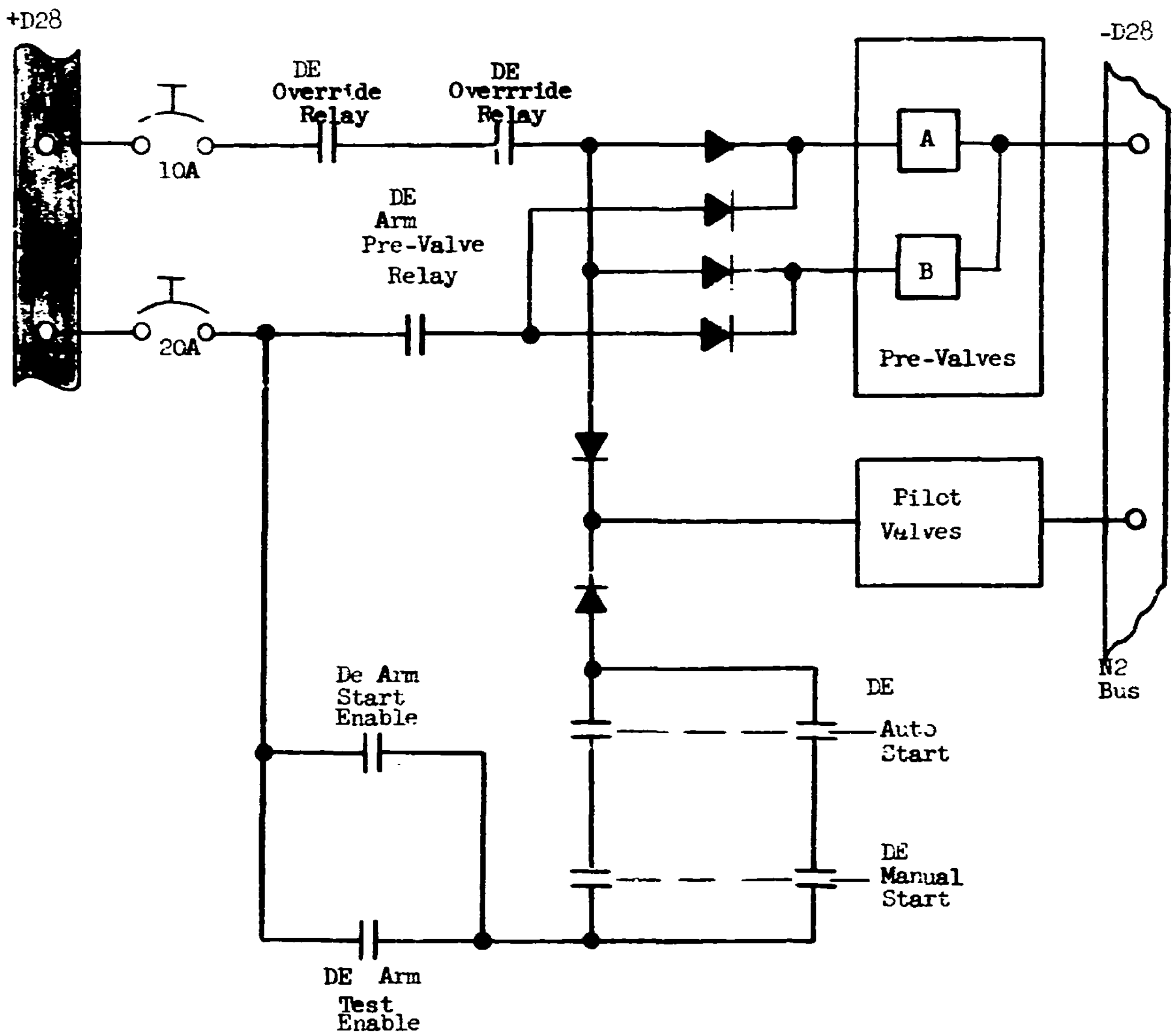


Figure 3.9-3
DPS Pre-Valve & Pilot
Valve Schematic

3.10 SOLENOID PILOT VALVES (DPS & APS)

The solenoid pilot valves are provided to control the flow of fuel against pistons which hydraulically drive the ball valves. The ball valves control the main flow of propellants to the chamber. A cross-sectional view of the pilot valves for the DPS and APS are shown in Figures 3.10-1 and 3.10-2, respectively, along with the fluid interfaces for normal and single-point failure operation. Materials exposed to the fluid medium for these conditions are identified and discussed in Section 4.

A manual or auto "descent engine on" signal provides a relay contact path from the DECA power circuit breaker (20A) to the DPS Pilot Valves. Power can also be supplied from the Descent Engine Override circuit breaker (10A) by operating the Descent Engine Override switch (Ref. Figure 3.9-3).

The failure modes for these valves are the same as for the Pre-Valves described in Para. 3.9.

The APS pilot valves are powered from the CDR and LMP AELD circuit breakers (7.5A) in parallel for Auto Engine On, Abort Stage or Manual Engine Start commands (Ref. Figure 3.9-2).

Although the heating effect is greater (>200 watts), the same operational constraints apply i.e. valve is only powered for engine firing which results in propellant flow more than sufficient to dissipate the energy input. Therefore, such a condition is incapable of providing any appreciable pressure rise to the related system.

There has been only one occurence where this valve has experienced a propellant breakthrough. This failure occurred at the descent engine vendor on 7 June 1966 where the solenoid was partially shorted resulting from propellant leakage into the solenoid (Failure Report # FST 18884). Corrective action provided an improved sealing capability to the solenoid coil by EO C104619-E2, effective on solenoid valves 128, 130 and subs, descent engine 1020 and subs. There have been no additional failures of propellant breakthrough.

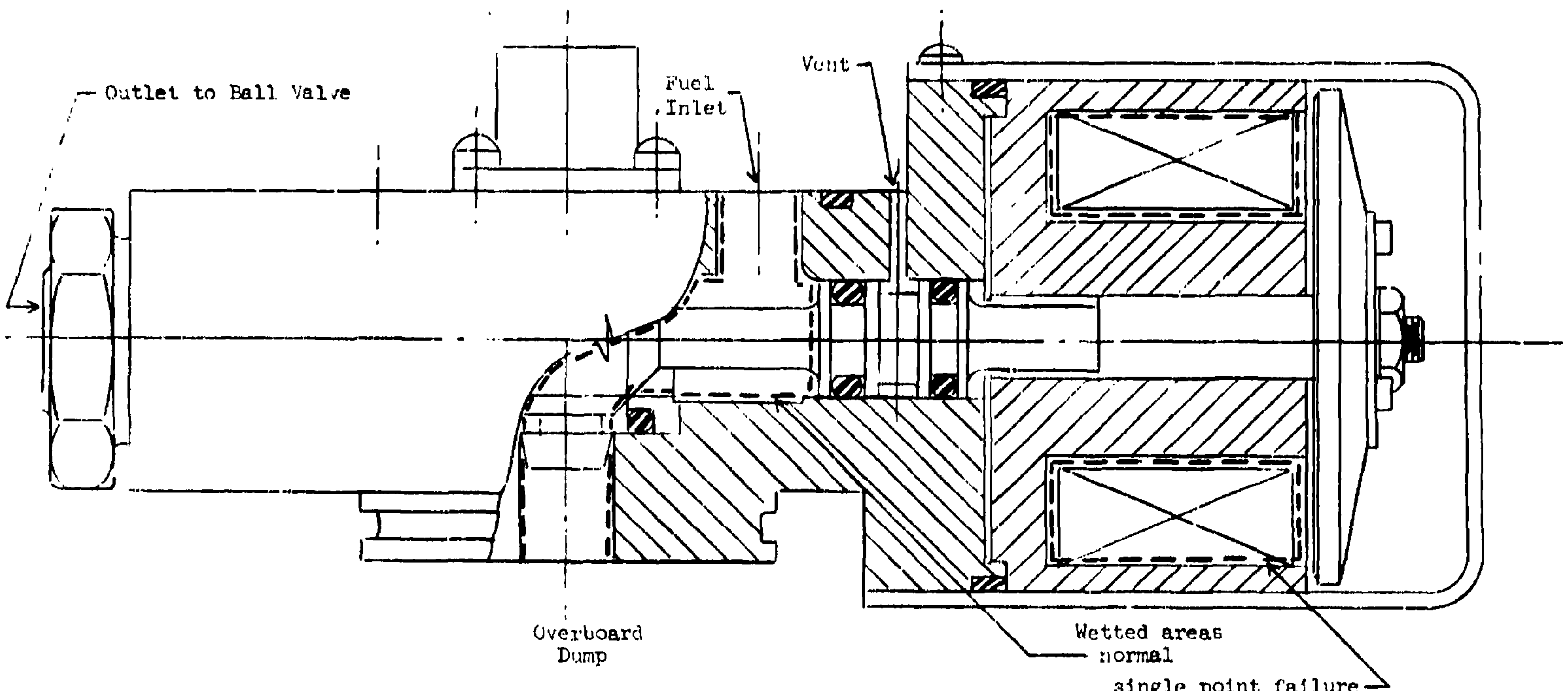


Figure 3.10-1
APS Pilot Valve

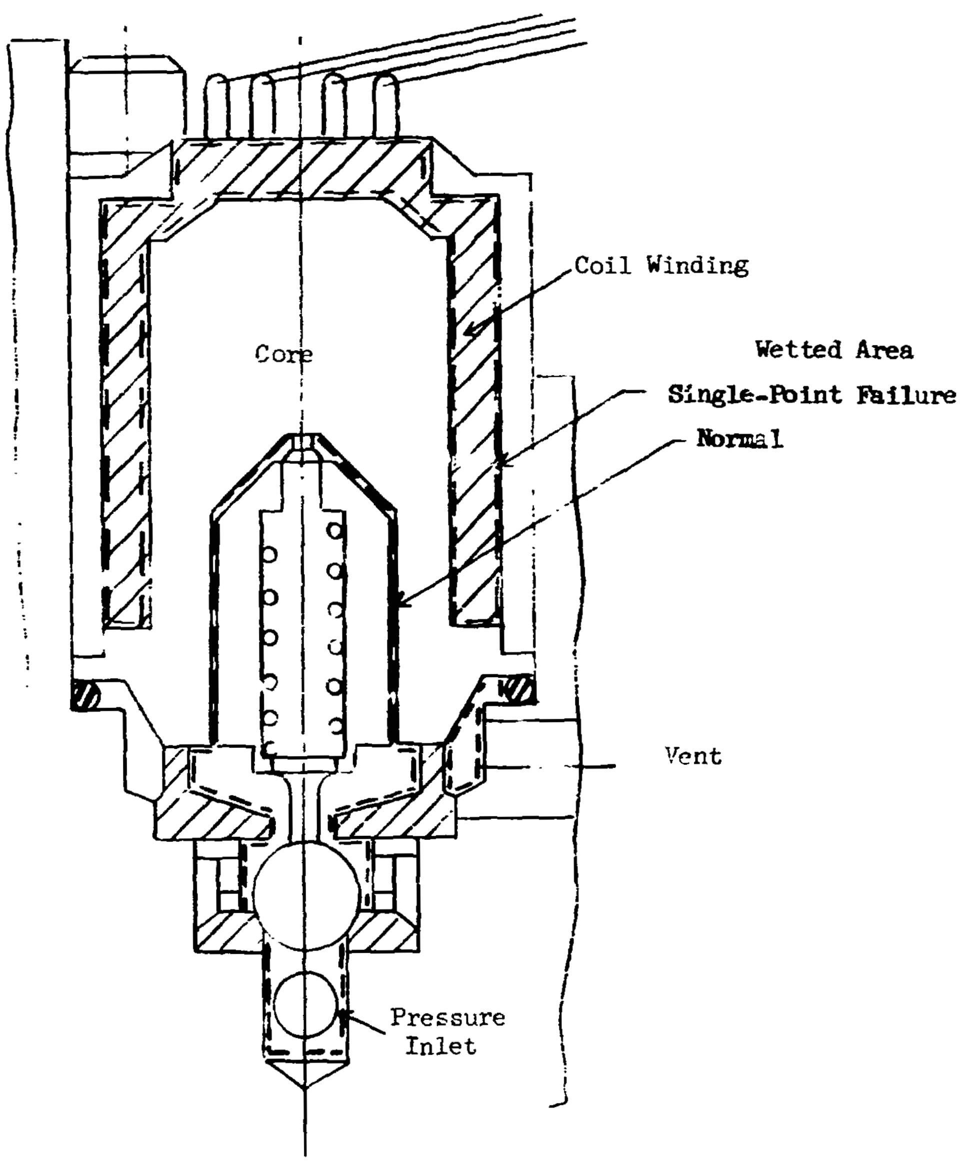


Figure 3.10-2
DPS Pilot Valve

4. MATERIALS COMPATIBILITY

4.1 INTRODUCTION

This section presents a review of material compatibility for those materials exposed to N_2O_4, A-50, O_2 and KOH. Emphasis has been placed on the compatibility of the non-metallic materials in each subsystem exposed to these fluids in normal and single-point failure modes of operation. These compatibility considerations have included: 1) evaluation of the material degradation when exposed to the fluid at normal operating temperatures i.e. is it dissolved or not, 2) is the material impact or shock sensitive when exposed to the fluid, and 3) is it capable of reacting if heated to a high temperature? For the electro-mechanical instrumentation devices, an estimate of pressure rise in the system as a result of assumed combustion of non-metallics has been computed. In addition, a general discussion of materials compatibility is included for those items exposed to an overboard oxidizer leak.

4.2 NITROGEN TETROXIDE (N_2O_4)

A review of the non-metallic materials normally exposed to the propellant oxidizer in RCS, APS, and DPS (see tables 4.2-1, 4.2-2 and 4.2-3, respectively) indicates that only Teflon, Kynar, and Carboxy-Nitroso-Rubber are used. Teflon is used in static, sliding and impact seals. Kynar is used in sliding and impact seals. However, with the exception of the RCS quad check valves, it is limited to operation in the test/servicing quick disconnects. Carboxy-Nitroso-Rubber (CNR) is used in static and sliding seals, and as an impact seal in the RCS quad check valve. This check valve sees only helium and N_2O_4 vapor, since the **liquid oxidizer is contained within a Teflon bladder.**

Impact data at up to 70 ft-lbs (limits of test) indicated no reaction in N_2O_4 for Teflon and Kynar. No impact data are available for CNR other than component and system tests. Available data indicate that all three materials are compatible with

4.2 cont'd

N_2O_4 and are not attacked by extended liquid or vapor exposure at normal operating temperatures.

Limited data on Teflon decomposition products exposed to oxidizer vapors in a vacuum at 200,000 feet indicate no reaction (Reference 7). Otherwise there are no data available on the exposure of hot (over 160°F) Teflon, Kynar or CNR to N_2O_4 liquid or vapor at operating pressures of 200 psi.

Butyl rubber is used as a secondary static seal in the Propellant Level Detector and Explosive Valves. Data indicate this material has limited compatibility in N_2O_4 liquid. Extended exposure tends to soften the material and make it tacky. No impact or elevated temperature data are available for this material; however, it is not used under those conditions.

Non-metallic materials used in electro-mechanical devices (such as the Propellant Quantity Gaging System, Temperature Transducer, Absolute Pressure Transducer and Solenoid Valve) require a structural metal case failure to expose non-metallic components of the electrical system to N_2O_4. Upon exposure, these non-metallic materials would be attacked by the N_2O_4 at normal temperatures and cause leakage through the device. These materials are identified in Tables 4.2-1 through 4.2-3. No impact or elevated temperature reaction data are available.

Material compatibility testing references shown in Tables 4.2-1, -2, and -3 are presented in Para. 4.8. The materials are compatible with the fluid for static or impact conditions as demonstrated by the references. Leaks through transducer metal cases into areas where no compatibility reference is shown are intended to indicate that: 1) no data are available, and 2) the generic type materials exposed in this area are generally attacked by the fluid.

TABLE 4.2-1; LM RCS OXIDIZER SIDE NON-METALLIC MATERIALS LIST

COMPONENT NAME AND IDENTIFICATION NUMBER	MATERIAL	APPLICATION	MODE NORMAL OR SINGLE MALFUNCTION	TYPE OF CONTACT	COMPATIBILITY INFORMATION & REFS. (PARA 4.8)	
					STATIC	IMPACT
Oxidizer Tank LSC-310-405	Teflon TFE & FEP	Expulsion Bladder	N	Fluid	4	1
	Teflon TFE	Space -Top of Stand-Pipe Gasket-Static-Base Cover to Tank Vent Line-Strings	N	Fluid	4	1
	Teflon TFE/FEP	Pad -He Deflector	N	Fluid	4	1
Quick Disconnect LSC-310-311	Kynar	Impact Poppet Seal He Servicing	M.-Failure of Quad. Check Valve	Vapor	4	2
Quad. Check Valve LSC-310-306	Nitroso	Impact Poppet Seal	M.-Failure of Propellant	Vapor	8	
	Kynar	Sliding Shaft Guide	M.-Tank Bladder	Vapor	4	2
Relief Valve LSC-310-307	Teflon	Impact Seal	M.-Failure of Burst Disc	Vapor	4	1
	Kynar	Sliding Shaft Seal		Vapor	4	2
Vent/Propellant Coupling LSC-310-401	Kynar	Impact Poppet Seal - N_2O_4 Servicing	N	Liquid	4	2

TABLE 4.2-1; (Cont'd)

COMPONENT NAME AND IDENTIFICATION NUMBER	MATERIAL	APPLICATION	MODE NORMAL OR SINGLE MALFUNCTION	TYPE OF CONTACT	COMPATIBILITY INFORMATION & REFS. (PARA 4.8)	
					STATIC	IMPACT
Solenoid Valve	Teflon	Impact Seat	N	Liquid	4	1
LSC-310-403	RTV-30	Solenoid Potting	M.-Failure of Seal Weld	Liquid	Incompatible	
RCS Engine Valve	Teflon	Impact Seat	N	Liquid	4	1
LSC-310-130	Lacquer (3M250,248)	Coil Insulation Potting Compound	M.-Failure of Weld	Liquid	Incompatible	
Pressure Transducer LSC-360-601	Glass (0.1gms est.)	Vacuum Seal Joint For Wire Feed Through	M.-Failure of Bourdon Tube	Liquid	Compatible	
	Epoxylite-6203 (0.1gms est.)	Wet Winding Agent For Sensor Coils	M.-Failure of Bourdon Tube	Liquid	Incompatible	
	Polyester per Mil-I-631 Type G (0.0001gms est.)	Coil Spacer	M.-Failure of Bourdon Tube	Liquid	Incompatible	
	Polyester Film	Coil Insulator	M.-Failure of Bourdon Tube	Liquid	Incompatible	
	Acrylic Adhesive Tape (0.001gms est)					

TABLE 4.2-1; (Cont'd)

COMPONENT NAME AND IDENTIFICATION NUMBER	MATERIAL	APPLICATION	MODE NORMAL OR SINGLE MALFUNCTION	TYPE OF CONTACT	COMPATIBILITY INFORMATION & REFS. (PARA 4.8)	
					STATIC	IMPACT
Pressure Transducer LSC-360-601	Loctite (0.00001 gm est)		M.-Failure of Bourdon Tube	Liquid	Incompatible	

TABLE 4.2-2; LM APS OXIDIZER SIDE NON-METALLIC MATERIALS LIST

COMPONENT NAME AND IDENTIFICATION NUMBER	MATERIAL	APPLICATION	MODE NORMAL OR SINGLE MALFUNCTION	TYPE OF CONTACT	COMPATIBILITY INFORMATION & REFS. (PARA 4.8)	
					STATIC	IMPACT
Oxidizer Tank LSC-280-70-5	Teflon-TFE	P.L.D. Primary Raco Seal (Jacket) Static	N	Liquid	4	1
	Butyl Rubber B591-8	P.L.D. Secondary Seal Static	M.-Failure of Primary Seal	Vapors	10	
	Butyl Rubber B591-8	Bleed Port Static Seal Washer-Tank Cover	N	Vapors	10	
Temperature Transducer LSC-360-605-303	Monsanto-05124 Mixed Isomeric-5 Ring Polyphenyl Ether (1.0gms est.)	Heat Transport Fluid Mixed with Aluminum Power	M.-These materials are exposed to fluid only upon rupture of the outer case which is 304 stainless steel.	Liquid		
	Epoxylite 6203 (4.0gms est)	Support Fiberous Asbestos	M. "	Liquid		
	Bondmaster M773A/B (8.0gms est)	Potting Compound	M. "	Liquid		
	Fiberous Asbestos (2.0gms est)	Cushion For Ceramic Element Tube	M. "	Liquid		

TABLE 4.2-2; (Cont'd)

COMPONENT NAME AND IDENTIFICATION NUMBER	MATERIAL	APPLICATION	MODE NORMAL OR SINGLE MALFUNCTION	TYPE OF CONTACT	COMPATIBILITY INFORMATION & REFS. (PARA 4.8) STATIC	IMPACT
Temperature Transducer LSC-360-605-303	Solder Glass (1.0gms est)	Insulator-Element Wire	M. These materials are exposed to fluid only upon rupture of the outer case which is 304 stainless steel	Liquid		
	Ceramic Tube (10 gms est)	To Construct Element	M. "	Liquid		
	Varglass Sleeving (0.00001gm est)	Insulator-Feed Wire	M. "	Liquid		
	Teflon Shrink Tube (0.00001gm est)	Insulator/Strain Relief	M. "	Liquid		
	Teflon Jacketed Cable (30gms est)	Wire-Mil-W-16878/4A	M. "	Liquid		

TABLE 4.2-2; (Cont'd)

COMPONENT NAME AND IDENTIFICATION NUMBER	MATERIAL	APPLICATION	MODE NORMAL OR SINGLE MALFUNCTION	TYPE OF CONTACT	COMPATIBILITY INFORMATION & REFS. (PARA 4.8)	
					STATIC	IMPACT
Pressure Relief Valve LSC-270-717-15	Teflon	Static Burst Disc Seal	N	Vapors	4	
	Teflon	Sliding Cap Seal	M	Vapors	4	2
	Nitroso	Static Seal		Vapors	8	
Fill and Test Disconnects LSC-270-813-25-27	Teflon	Impact Poppet Seal	N	Vapors and Liquid	4 4	2 2
Quad. Check Valves LSC-270-817	Teflon, FEP	Impact Poppet Seals	N	Liquid	4	2
	Teflon, FEP	Impact Poppet Seals	M	Vapors	4	2
Pressure Transducer LSC-360-601	Glass (0.1gm est)	Vacuum Seal Joint for Wire Feed Through	M	Liquid	Compatible	
	Epoxylite 6203 (o.1gm est)	Wet Winding Agent for Sensor Coils	M	Liquid	Incompatible	
	Polyester Per Mil-I-631 (0.001 gm est)	Coil Spacer	M	Liquid	Incompatible	

TABLE 4.2-2; (Cont'd)

COMPONENT NAME AND IDENTIFICATION NUMBER	MATERIAL	APPLICATION	MODE NORMAL OR SINGLE MALFUNCTION	TYPE OF CONTACT	COMPATIBILITY INFORMATION & REFS. (PARA 4.8)	
					STATIC	IMPACT
Pressure Transducer LSC-360-601	**Loctite** (0.00001 gm est)		M	**Liquid**	**Incompatible**	
	Polyester Film Acrylic Adhesive Adhesive Tape (0.001gm est)	**Coil Insulator**	M	**Liquid**	**Incompatible**	
Absolute Pressure Transducer LSC-360-624-1	**Epoxy-**BR610 (5.0gms est)	**Internal Components to Outer Shell**	M	**Liquid**	**Incompatible**	
	Silicone Strain Gages (0.1gm est)			**Liquid**	**Incompatible**	
	Ceramic (1.0gm est)			**Liquid**		
	Glass (0.2gm est)			**Liquid**	**Compatible**	

TABLE 4.2-2; (Cont'd)

COMPONENT NAME AND IDENTIFICATION NUMBER	MATERIAL	APPLICATION	MODE NORMAL OR SINGLE MALFUNCTION	TYPE OF CONTACT	COMPATIBILITY INFORMATION & REFS. (PARA 4.8) STATIC	IMPACT
Propellant Level Detector LSC-270-801	Teflon	Internal Components	M.-These materials are exposed to fluid only upon rupture of the outer case, which is 347 stainless steel.	Liquid		
	Buna-N-Type -N .01 lbs.		M. "	Liquid		
	Maga Filler		M. "	Liquid		
	RTV-20 Potting .021 lbs.		M. "	Liquid		
	Stycast 1090 Cat. 11 .007 lbs.		M. "	Liquid		
Explosive Flow Valve LSC-270-819-9-7A	Butyl B-318-7	Redundant Seal (Pyrotechnic) Static	M.-Only in Post Fired Condition	Liquid	6	
Fill and Test Disconnects LSC-270-805-2 703-1	Kynar	Impact-Poppet Seal	N	Liquid	4	2
	Kynar	Secondary Sliding Seal	M	Liquid	4	2

TABLE 4.2-3; LM DPS OXIDIZER SIDE NON-METALLIC MATERIALS LIST

COMPONENT NAME AND IDENTIFICATION NUMBER	MATERIAL	APPLICATION	MODE NORMAL OR SINGLE MALFUNCTION	TYPE OF CONTACT	COMPATIBILITY INFORMATION & REFS. (PARA 4.8)	
					STATIC	IMPACT
LM D/S Oxidizer Tank LSC 280-4	Teflon-TFE	Seal-Gland Static	N	Liquid	4	
	Teflon-TFE	Raco Seal Jacket Static	N	Liquid	4	
	Rulon A	Level Sensor Support Static	N	Liquid	11	
	Teflon-TFE	Diffuser Seal Static	N	Liquid	4	
	Nitroso	Diffuser Seal Static	M	Liquid	8	
Propellant Quantity Gaging System LSC-270-00009	Rulon A .26 lbs.	Tank Mount to Probe Insulator Static	N	Liquid	11	
	Teflon	Flange Lining Static	N	Liquid	4	
	Teflon .055 lbs.	Wire Cover Static	N	Liquid	4	
	Glass	Portion of Herm. Seal	M	Liquid	Compatible	
	Stycast 1090 .3 lb	Electronic Potting	M	Liquid	Incompatible	
	RTV 20 .017 lbs.	Potting Compound	M	Liquid	Incompatible	
Solenoid Latch Valve (Lunar Dump) LSC-310-403-305	Teflon	Impact Seat	N	Vapors	4	1
	RTV-30	Solenoid Potting Compound	M.-Case Failure	Vapors	Incompatible	

TABLE 4.2-3; (Cont'd)

COMPONENT NAME AND IDENTIFICATION NUMBER	MATERIAL	APPLICATION	MODE NORMAL OR SINGLE MALFUNCTION	TYPE OF CONTACT	COMPATIBILITY INFORMATION & REFS. (PARA 4.8)	
					STATIC	IMPACT
Squib Valve LSC-270-819	Butyl B318-7	Redundant Seal Pyrotechnic-Static	M.-Only in Post Fired Condition	Liquid	6	
Quad. Check Valves LSC-270-817-3	Teflon, FEP	Impact Poppet Seat	N	Liquid	4	1
	Teflon, FEP	Impact Poppet Seat	M	Liquid	4	1
Coupling Manual Disconnect- Propellant Servicing LSC-270-802	Teflon	Impact-Sliding Poppet Seal	N	Liquid	4	1
	Teflon	Secondary Sliding Seal	M	Liquid	4	1
Relief Valve LSC-270-818-5	Teflon-FEP	Impact Poppet Seat	M	Liquid	4	1
	Kynar	Static Filter Seal	M	Liquid	4	2
Coupling-Quick Disconnect LSC-270-813	Teflon	Impact Poppet Seal	N	Liquid	4	1
	Teflon	Secondary Sliding Seal	M	Liquid	4	1

TABLE 4.2-3; (Cont'd)

COMPONENT NAME AND IDENTIFICATION NUMBER	MATERIAL	APPLICATION	MODE NORMAL OR SINGLE MALFUNCTION	TYPE OF CONTACT	COMPATIBILITY INFORMATION & REFS. (PARA 4.8)	
					STATIC	IMPACT
Descent Engine Oxidizer Inlet Line TRW 108611-5	Teflon	"O" Ring Static Flange Seal	N	Liquid	4	
Oxidizer Duct TRW 108621-6	Teflon	"O" Ring Static Flange Seal	N	Liquid	4	
Flow Control Valve TRW 401574-4	Nitroso	Downstream Static Flange Seal	N	Liquid	8	
	Teflon	Upstream Static Flange Seal	N	Liquid	4	
Flow Control Valve Elbow TRW 402614-4	Nitroso	Upstream Static Flange Seal	N	Liquid	8	
	Teflon	Downstream Static Flange Seal	N	Liquid	4	
Flow Control Valve Pintle Shaft Seals	Nitroso	Sliding Seals	N	Liquid	8	
Element Assembly TRW 111381-5	Teflon	Support Ring Sliding Bearing	N	Liquid	4	1
Oxidizer Shut Off Valve TRW C104619-8	Teflon	Ball Valve Sliding Seal	N	Liquid	4	1

TABLE 4.2-3; (Cont'd)

COMPONENT NAME AND IDENTIFICATION NUMBER	MATERIAL	APPLICATION	MODE NORMAL OR SINGLE MALFUNCTION	TYPE OF CONTACT	COMPATIBILITY INFORMATION & REFS. (PARA 4.8)	
					STATIC	IMPACT
Oxidizer Tank Temperature Transducer LSC-360-605-303	Mixed Isomeric 5 Ring Polyphenyl Ether (1.0gms est)	Heat Transport Fluid	All Components are internal to outer stainless steel housing. Upon its failure internal components will be exposed to liquid and malfunction.	Liquid		
	Epoxylite 6203 (4.0gms est)	Support Fiberous Asbestos	"	Liquid		
	Bondmaster M773 A/B (8.0gms est)	Potting Compound	"	Liquid		
	Fiberous Asbestos (2.0gms est)	Cushion for Ceramic Element Tube	"	Liquid		
	Solder Glass (1.0gms est)	Insulator Element Wire	"	Liquid		
	Ceramic Tube (10.gms est)	Construction of Element Assembly	"	Liquid		

TABLE 4.2-3; (Cont'd)

COMPONENT NAME AND IDENTIFICATION NUMBER	MATERIAL	APPLICATION	MODE NORMAL OR SINGLE MALFUNCTION	TYPE OF CONTACT	COMPATIBILITY INFORMATION & REFS. (PARA 4.8)	
					STATIC	IMPACT
Oxidizer Tank Temperature Transducer LSC-360-605-303	Varglass Sleeving (0.00001gm est)	Insulator; Feed Wire	All components are internal to outer stainless steel housing. Upon its failure internal components will be exposed to liquid and malfunction.	Liquid		
	Teflon, R (0.00001gm est)	Insulator Shrink Tubing	"	Liquid		
	Wire-Teflon Jacketed (30gms est)	Mil-W-16878/4A Wire	"	Liquid		
Absolute Pressure Transducer LSC-360-601-xxx-3	Epoxylite-6203 (0.1gm est)	Wet Winding Agent for Sensor Coils	All components are internal to outer stainless steel housing. Upon its failure, internal components will be exposed to liquid and malfunction.	Liquid		
	Polyester Forms Mil-I-631-Type-G (0.0001gm est)	Coil Spacer	"	Liquid		

TABLE 4.2-3; (Cont'd)

COMPONENT NAME AND IDENTIFICATION NUMBER	MATERIAL	APPLICATION	MODE NORMAL OR SINGLE MALFUNCTION	TYPE OF CONTACT	COMPATIBILITY INFORMATION & REFS. (PARA 4.8)	
					STATIC	IMPACT
Absolute Pressure Transducer LSC-360-601-xxx-3	Glass (0.1gm est)	Glass/Metal Vacuum Seal	All components are internal to outer stainless steel housing. Upon its failure, internal components will be exposed to liquid and malfunction.	Liquid		
	Loctite (0.0001gm est)	Screw Sealant	"	Liquid		
	Polyester Film Acrylic Adhesive Tape	Coil Insulator	"	Liquid		
Absolute Pressure Transducer LSC-360-624-xxx-2	Epoxylite 6203 (5.0gms est)	Base Coat on Diaphragm and Bonding Agent for Silicon Strain Gages	All materials listed here are internal to diaphragm. Failure of which exposes these non-metallics to liquid.	Liquid		
	Silicon Strain Gages (0.1gm est)	4 Bonded to Diaphragm	"	Liquid		

TABLE 4.2-3; (Cont'd)

COMPONENT NAME AND IDENTIFICATION NUMBER	MATERIAL	APPLICATION	MODE NORMAL OR SINGLE MALFUNCTION	TYPE OF CONTACT	COMPATIBILITY INFORMATION & REFS. (PARA 4.8)	
					STATIC	IMPACT
Absolute Pressure Transducer LSC-360-624-xxx-2	Glass (o.2gm est)	Metal/Glass Seals Wire Feed Through	All Materials listed here are internal to diaphram. Failure of which exposes these non-metallics to liquid.	Liquid		

4.3 AEROZINE-50 (A-50)

A review of the non-metallic materials normally exposed to the propellant fuel in RCS, APS and DPS (See Tables 4.3-1, 4.3-2 and 4.3-3, respectively) indicate that Teflon, Kynar, Ethelyene Propylene Rubber (EPR) and Butyl Rubber are used. Teflon is used in static, sliding and impact seals. Kynar is used in sliding and impact seals. However, with the exception of the RCS quad check valves and descent pilot valve, it is limited to operation in the test/servicing quick disconnects. Butyl rubber is used in static and sliding seals and as an impact seal in the RCS quad check valve. This check valve sees only helium and A-50 vapor, since the fuel is contained within a Teflon bladder. EPR is used in static, sliding and impact seals in the ascent and descent propulsion prevalves and pilot valves.

Impact data at up to 70 ft-lb (limits of test) indicate no reaction in A-50 for Kynar (Reference 5). Because A-50 is not considered mechanical shock sensitive (Reference 6), this type evaluation is not normally conducted on exposed materials. Other than component and system tests, no impact data are available for Teflon, EPR and Butyl rubber.

Available data indicate that all four materials are compatible with the fuel at normal operating temperatures. In addition, system level tests have indicated no problems with these four seal materials.

Recent tests conducted at Atlantic Research indicate that fuel vapors can be ignited as a monopropellant at approximately 450°F, and the liquid becomes a monopropellant at approximately 550°F. Teflon and EPR exposed in these environments did not affect the reaction temperatures. Data on the effects of Kynar, or Butyl rubber in these environments are not available.

Non-metallic materials used in electro-mechanical devices such as the Propellant Quantity Gaging System, Temperature Transducer, Absolute Pressure Transducer, Solenoid Valve, and Engine Solenoid Pilot Valve require a structural metal case failure to expose non-metallic components of the electrical system to A-50. Upon exposure, these non-metallic materials would be attacked by the A-50 at normal

4.3 cont'd

temperatures and cause leakage through the device. These materials are identified in Tables 4.3-1 through 4.3-3. No impact or elevated temperature reaction data on these materials exposed to A-50 are available. However, as previously stated, the fuel itself becomes a monopropellant at temperatures of 450 and 550°F for vapor and liquid respectively.

Material compatibility testing references shown in Tables 4.3-1, -2 and -3 are presented in Para. 4.8. The materials are compatible with the fluid for static or impact conditions as demonstrated by the references. Leaks through transducer metal cases into areas where no compatibility reference is shown are intended to indicate that: 1) no data are available, and 2) the generic type materials exposed in this area are generally attacked by the fluid.

TABLE 4.3-1; LM RCS FUEL SIDE NON-METALLIC MATERIALS LIST

COMPONENT NAME AND IDENTIFICATION NUMBER	MATERIAL	APPLICATION	MODE NORMAL OR SINGLE MALFUNCTION	TYPE OF CONTACT	COMPATIBILITY INFORMATION & REFS. (PARA 4.8) STATIC	IMPACT
Fuel Oxidizer Tank LSC-310-405	Teflon TFE & FEP	Expulsion Bladder	N	Fluid	4	
	Teflon TFE	Spacer-Top Of Stand-Pipe Gasket-Static Base Cover To Tank Vent Line-Strings	N	Fluid	4	
	Teflon TFE & FEP	Pad-He Deflector	N	Fluid	4	
Quick Disconnect LSC-310-311	Kynar	Impact Poppet Seal He Servicing	M - Failure of Quad Check Valve	Vapor	4	2
Quad Check Valve LSC-310-306	Butyl B591-8	Impact Poppet Seal	M - Failure of Propellant Tank	Vapor	12	
	Kynar	Sliding Shaft Guide	M Bladder	Vapor	4	2
Vent/Propellant Coupling LSC 310-401	Kynar	Impact Poppet Seal - N_2O_4 Servicing	N	Liquid	4	2
Solenoid Valve LSC-310-403	Teflon	Impact Seal	N	Liquid	4	1
	RTV-30 1 gm	Solenoid Potting	M-Failure of Seal Seal Weld	Liquid	Incompatible.	
Relief Valve LSC-310-307	Teflon	Impact Seal	M Failure of Burst Disc	Vapor	4	1
	Kynar	Sliding Shaft Seal		Vapor	4	2

TABLE 4.3-1 (Continued)

COMPONENT NAME AND IDENTIFICATION NUMBER	MATERIAL	APPLICATION	MODE NORMAL OR SINGLE MALFUNCTION	TYPE OF CONTACT	COMPATIBILITY INFORMATION & REFS. (PARA 4.8)	
					STATIC	IMPACT
RCS Engine Valve	Teflon	Impact Seat	N	Liquid	4	1
LSC-310-130	Lacquer (3M250,248)	Coil Insulation Potting Compound	M Failure of Weld	Liquid	Incompatible	
Pressure Transducer LSC-360-601	Glass (0.1 gms est)	Vacuum Seal Joint For Wire Feed Through	M Failure of Bourdon Tube	Liquid	Compatible	
	Epoxylite 6203 (0.1 gms est)	Wet Winding Agent For Sensor Coils	M Failure of Bourdon Tube	Liquid	Incompatible	
	Polyester-Per Mil-I-631 Type G (0.001 gms est)	Coil Spacer	M	Liquid		
	Polyester Film - Acrylic Adhesive Tape (0.001 gms est)	Coil Insulator	M	Liquid		
	Loctite (0.00001 gms est)		M	Liquid		

TABLE 4.3-2; LM APS FUEL SIDE NON-METALLIC MATERIALS LIST

COMPONENT NAME AND IDENTIFICATION NUMBER	MATERIAL	APPLICATION	MODE NORMAL OR SINGLE MALFUNCTION	TYPE OF CONTACT	COMPATIBILITY INFORMATION & REFS. (PARA 4.8) STATIC	IMPACT
Fuel tank LSC-280-70-	Teflon-TFE	P.L.D. Primary Raco Seal (Jacket) Static	N	Liquid	4	1
	Butyl Rubber B591-8	P.L.D.-Secondary Seal Static	M - Failure of Primary Seal	Vapors	12	
	Butyl Rubber B591-8	Bleed Port Static Seal Washer-Tank Cover	N	Vapors	12	
Temperature Transducer LSC-360-605-303	Monsanto-05124 Mixed Isomeric 5 Ring Polyphenyl Ether (1.0 gms est)	Heat Transport Fluid Mixed With Aluminum Powder	M These Materials are Exposed to Fluid Only Upon Rupture of the Outer Case which is 304	Liquid		
	Epoxylite 6203 (4.0 gms est)	Support Fiberous Asbestos	M Stainless Steel	Liquid		
	Bondmaster-M773A/B (8.0 gms est)	Potting Compound	M	Liquid		
	Fiberous Asbestos (2.0 gms est)	Cushion For Ceramic Element Tube	M	Liquid		

TABLE 4.3-2 (Continued)

COMPONENT NAME AND IDENTIFICATION NUMBER	MATERIAL	APPLICATION	MODE NORMAL OR SINGLE MALFUNCTION		TYPE OF CONTACT	COMPATIBILITY INFORMATION & REFS. (PARA 4.8) STATIC	IMPACT
Temperature Transducer, LSC-360-605-303 (Cont'd)	Solder Glass (1.0 gms est)	Insulator-Element Wire	M	These Materials are Exposed to Fluid Only Upon Rupture Of The Outer Case Which is 304 Stainless Steel	Liquid		
	Ceramic Tube (10 gms est)	To Construct Element	M		Liquid		
	Varglass Sleeving (0.00001 gms est)	Insulator - Feed Wire	M		Liquid		
	Teflon-Shrink Tube (0.00001 gms est)	Insulator/Strain Relief	M		Liquid		
	Teflon Jacketed Cable (30 gms est)	-Wire-Mil-W-1687/4A	M		Liquid		
Propellant Lever Detector LSC-270-801	Teflon	Internal Components	M	These Materials Are Exposed To Fluid Only Upon Rupture Of The Outercase, Which Is 347 Stainless Steel	Liquid		
	Buna-N-Type-N		M		Liquid		
	Maga Filler		M		Liquid		
	RTV-20 Potting		M		Liquid		
	Stycast 1090		M		Liquid		

TABLE 4.3-2 (Continued)

COMPONENT NAME AND IDENTIFICATION NUMBER	MATERIAL	APPLICATION	MODE NORMAL OR SINGLE MALFUNCTION	TYPE OF CONTACT	COMPATIBILITY INFORMATION & REFS. (PARA 4.8) STATIC	IMPACT
Explosive Flow Valve LSC-270-819-9-7A	Butyl-B-318-7	Redundant Seal (Pyrotechnic) Static	M Only In Post Fired Condition	Liquid	6	
Fill And Test Disconnects	Kynar	Impact - Poppet Seal	N	Liquid	4	5
LSC-270-805-2,-702-1	Kynar	Secondary Sliding Seal	M	Liquid	4	5
Pressure Relief Valve LSC-270-717-15	Teflon	Static Burst Disc Seal	N	Vapors	4	
	Teflon	Sliding Cap Seal	M	Vapors	4	
	Butyl B591-8	Static Seal		Vapors	12	
Fill And Test Disconnects, LSC-270-813-25,-27	Teflon	Impact Poppet Seal	N	Vapors and Liquid	4 4	
Quad Check Valves LSC-270-817	Teflon, FEP Teflon, FEP	Impact Poppet Seal Impact Poppet Seal	N M	Liquid and Vapors	4 4	
Pressure Transducer LSC-360-601	Glass (0.1 gms est)	Vacuum Seal Joint For Wire Feed Through	M	Liquid	Compatible	
	Epoxlite 6203 (0.1 gms est)	Wet Winding Agent For Sensor Coils	M	Liquid	Incompatible	

TABLE 4.3-2 (Continued)

COMPONENT NAME AND IDENTIFICATION NUMBER	MATERIAL	APPLICATION	MODE NORMAL OR SINGLE MALFUNCTION	TYPE OF CONTACT	COMPATIBILITY INFORMATION & REFS. (PARA 4.8) STATIC	IMPACT
Pressure Transducer LSC-360-601 (Cont'd)	Polyester Per Mil-I-631 (0.001 gms est)	Coil Spacer	M	Liquid	Incompatible	
	Loctite (0.00001gms est)		M	Liquid	Incompatible	
	Polyester Film Acrylic Adhesive Tape (0.001 gms est)	Coil Insulator	M	Liquid	Incompatible	
A/S Engine PreValve LSC-270-00822	Ethylene Propylene Rubber	Sliding/Impact Seal E515-8	N	Liquid	10	
	RTV	Solenoid Potting	M Case Rupture	Liquid	Incompatible	
A/S Engine Valve Package Bell 8258-472225	Teflon FEP	Static Seal	N	Liquid	4	1
	Ethylene Propylene Rubber E515-8 E540-8	Sliding /Static Seal	N	Liquid	10	

TABLE 4.3-2 (Continued)

COMPONENT NAME AND IDENTIFICATION NUMBER	MATERIAL	APPLICATION	MODE NORMAL OR SINGLE MALFUNCTION	TYPE OF CONTACT	COMPATIBILITY INFORMATION & REFS. (PARA 4.8)	
					STATIC	IMPACT
Absolute Pressure Transducer LSC-360-624-1-31	**Epoxy-BR610** (5.0 **gms est**)	**Internal Components To Outer Shell**	M	**Liquid**	**Incompatible**	
	Silicon Strain Gages (0.1 **gms est**)			**Liquid**	**Incompatible**	
	Ceramic (1.0 **gms est**)			**Liquid**		
	Glass (0.2 **gms est**)			**Liquid**		

TABLE 4.3-3; LM DPS FUEL SIDE NON METALLIC MATERIALS LIST

COMPONENT NAME AND IDENTIFICATION NUMBER	MATERIAL	APPLICATION	MODE NORMAL OR SINGLE MALFUNCTION	TYPE OF CONTACT	COMPATIBILITY INFORMATION & REFS. (PARA 4.8)	
					STATIC	IMPACT
LM D/S Fuel Tank LSC-280-4	Teflon-TFE	Seal Gland-Static	N	Liquid	4	-
	Teflon-TFE	Raco Seal Jacket-Static	N	Liquid	4	-
	Rulon A	Level Sensor Support - Static	N	Liquid	11	-
	Teflon-TFE	Diffuser Seal-Static	N	Liquid	4	-
	Vistanex	Diffuser Seal-Static	M	Liquid	8	-
Propellant Quantity Gaging System LSC-270-00009	Rulon A .26 lb.	Tank Mount to Probe Insulator-Static	N	Liquid	11	-
	Teflon	Flange Lining-Static	N	Liquid	4	-
	Teflon .055 lb	Wire Cover-Static	N	Liquid	4	-
	Glass	Portion of Herm. Seal	M	Liquid	Compatible	
	Stycast 1090 .3 lb	Electronic Potting	M	Liquid	Incompatible	
	RTV 20 .017 lb	Potting Compound	M	Liquid	Incompatible	
Solenoid Latch Valve (Lunar Dump) LSC-310-403-305	Teflon	Impact Seat	N	Vapors	4	1
	RTV-30	Solenoid Potting Compound	M-Case Failure	Vapors	Incompatible	

TABLE 4.3-3; (cont'd)

COMPONENT NAME AND IDENTIFICATION NUMBER	MATERIAL	APPLICATION	MODE NORMAL OR SINGLE MALFUNCTION	TYPE OF CONTACT	COMPATIBILITY INFORMATION & REFS. (PARA 4.8)	
					STATIC	IMPACT
Squib Valve LSC-270-819	Butyl-B318-7	Redundant Seal Pyro-technic-Static	M - Only in Post Fired Condition	Liquid	6	-
Quad Check Valves - LSC-270-817-3	Teflon-FEP	Impact, Poppet Seat	N	Liquid	4	1
	Teflon-FEP	Impact, Poppet Seat	M	Liquid	4	1
Coupling, Manual Disconnect - Propellant Servicing LSC-270-802	Kynar	Impact-Sliding Poppet Seal	N	Liquid	4	5
	Kynar	Secondary Sliding Seal	M	Liquid	4	5
Relief Valve LSC-270-818-5	Teflon-FEP	Impact Poppet Seat	M	Liquid	4	1
	Kynar	Static Filter Seal	M	Liquid	4	2
Coupling-Quick Disconnect	Teflon	Impact-Poppet Seal	N	Liquid	4	1
LSC-270-813	Teflon	Secondary Sliding Seal	M	Liquid	4	1
D/S Engine-LSC-270-00600-27;29 Fuel Inlet Line-TRW108611-5	Teflon	"O" Ring Static Flange Seal	N	Liquid	4	-
Fuel Duct TRW-108621-6	Butyl-B591-8	"O" Ring Static Flange Seal	N	Liquid	12	-
Flow Control Valve TRW 401574-4	Butyl-B591-8	Downstream Static Flange Seal	N	Liquid	12	-
	Butyl-B-591-8	Upstream Static Flange Seal	N	Liquid	12	-

TABLE 4.3-3; (cont'd)

COMPONENT NAME AND IDENTIFICATION NUMBER	MATERIAL	APPLICATION	MODE NORMAL OR SINGLE MALFUNCTION	TYPE OF CONTACT	COMPATIBILITY INFORMATION & REFS. (PARA 4.8)	
					STATIC	IMPACT
Flow Control Valve Elbow TRW 402614-4	Butyl-B591-8	Upstream Static Flange Seal	N	Liquid	12	-
	Butyl-B591-8	Downstream Static Flange Seal	N	Liquid	4	-
Flow Control Valve Pintle Sheft Seals	Butyl-B591-8	Sliding Seals	N	Liquid	12	-
Element Assembly TRW 111381-5	Teflon	Support Ring Sliding Bearing	N	Liquid	4	1
Fuel Shut Off Valve TRW-C10469-8	Teflon	Ball Valve Sliding Seal	N	Liquid	4	1
LM D/S Engine Prevalves LSC-270-00600	Ethylene Propylene Rubber	Sliding/Impact/Static Seals E515-8	N	Liquid	10	-
	Potting Compound S-5370	Solenoid Potting	M	Liquid	Incom-patible	
LM D/S Engine Pilot Valve	Butyl-SR634-70	Static "O" Ring Seal	N	Liquid	12	-
	Ethylene Propylene Rubber	Static "O" Ring Seal Static Seal E515-8	N	Liquid	10	-
	Kynar	Impact Seal	N	Liquid	4	5

TABLE 4.3-3; (cont'd)

COMPONENT NAME AND IDENTIFICATION NUMBER	MATERIAL	APPLICATION	MODE NORMAL OR SINGLE MALFUNCTION	TYPE OF CONTACT	COMPATIBILITY INFORMATION & REFS. (PARA 4.8) STATIC	IMPACT
Fuel Tank Temperature Transducer LSC-360-605-303	Mixed isomeric 5 ring polyphenyl ether (1.0gms est)	Heat transport fluid	All components are internal to outer stainless steel housing. Upon its failure internal components will be exposed to liquid and malfunction	Liquid		
	Epoxylite 6203 (4.0gms est)	Support fiberous asbestos		Liquid		
	Bondmaster M773 A/B (8.0gms est)	Potting Compound		Liquid		
	Fiberous asbestos (2.0gms est)	Cushion for ceramic element tube		Liquid		
	Solder Glass (1.0gms est)	Insulator-Element Wire		Liquid		
	Ceramic tube (10.gms est)	Construction of element assembly		Liquid		
	Varglass sleeving (0.00001gms est)	Insulator-feed wire		Liquid		

TABLE 4.3-3; (cont'd)

COMPONENT NAME AND IDENTIFICATION NUMBER	MATERIAL	APPLICATION	MODE NORMAL OR SINGLE MALFUNCTION	TYPE OF CONTACT	COMPATIBILITY INFORMATION & REFS. (PARA 4.8)	
					STATIC	IMPACT
Fuel tank Temperature Transducer	Teflon, R (0.00001gms est)	Insulator Shrink Tubing	All components are internal to outer stainless steel housing. Upon its failure internal components will be exposed to liquid and malfunction	Liquid		
	Wire-teflon Jacketed (30gms est)	Mil-W-16878/4A wire		Liquid		
Absolute Pressure Transducer LSC-360-601-xxx-3	Epoxylite-6203 (0.1gms est)	Wet Winding Agent for Sensor Coils	All components are internal to outer stainless steel housing. Upon its failure internal components would be exposed to liquid and malfunction	Liquid		
	Polyester forms MIL-I-631-typeG (0.0001gms est)	Coil Spacer		Liquid		
	Glass (0.1gms est)	Glass/metal Vacuum seal		Liquid		
	Loctite (0.0001gms est)	Screw sealant		Liquid		
	Polyester film Acrylic adhesive tape	Coil insulator		Liquid		

TABLE (cont'd)

COMPONENT NAME AND IDENTIFICATION NUMBER	MATERIAL	APPLICATION	MODE NORMAL OR SINGLE MALFUNCTION	TYPE OF CONTACT	COMPATIBILITY INFORMATION & REFS. (PARA 4.8)	
					STATIC	IMPACT
Absolute Pressure Transducer LSC-360-624-xxx-2	Epoxylite 6203 (5.0gms est)	Base coat on diaphragm and bonding agent for silicon strain gages	All materials listed here are internal to diaphragm. Upon its failure internal components would be exposed to liquid and malfunction	Liquid		
	Silicon strain gages (0.1 gms est)	4 bonded to diaphragm		Liquid		
	Glass (0.2 gms est)	Metal/glass seals. Wire feed through.		Liquid		

4.4 OXYGEN

Non-metallic materials used in greater-than-20-psia oxygen systems are defined as Category "D" and are identified through the COMAT System; these are summarized in Table 4.4-1. Qualification for use in oxygen service is based on assembly level off-limit and qualification testing in accordance with the GAC controlling specification, LPL-521-2. Material application verification is provided through CTR tests which demonstrate the suitability of the material in terms of service oxygen pressure.

Three items (LSC-330-321, -390 and -505) have been identified as assemblies which utilize non-metallic materials in high pressure oxygen dynamic applications wherein the material may be subjected to impact loading. The non-metallics (Kel-F-81, Teflon, Viton A, Viton B, and Krytox 240 AC) were tested by the NASA/MSC Power and Propulsion Division to determine their GOX compatibility under mechanical impact with 10 foot-pounds at ambient temperatures and 2000 psia GOX pressure. The results of test, with 20 samples of each material tested, indicated no reactions; this substantiated the suitability of the materials for use in high pressure oxygen systems. The Kel-F-81 poppet seal in the 321 Fill Coupling is the only dynamic application for which impact data at normal, or greater than normal, operating pressure are not available. However, the dynamic application of this material occurs only during the oxygen fill cycle.

The oxygen qualification tests referenced in Table 4.4-1 and mentioned above demonstrate the suitability of the non-metallics used under conditions of no impact loading (static). Additionally, NASA has LOX or GOX impact test data available for all but three materials. Samples of the materials which have not been tested have been sent to WSTF for testing.

Three pressure transducers can, as a result of a single-point structural failure, expose non-metallics to high pressure GOX. The subject transducers meet the following requirements:

- o All sensors in absolute pressure transducers are leak checked at 1.5 to 2 times their rated pressure

4.4 cont'd

- o The sensing elements have a burst pressure rating of five times their rated pressure range
- o Proof pressure tests, during supplier and GAC PIT tests, demonstrate the integrity of the sensing element (calibration is performed after proof-pressure tests
- o Proof pressure tests exceed system usage operating pressure range

Should a rupture/leak of the sensing element occur, a) the reference chamber will contain two times rated range or 5,000 psia whichever is lower. (redundant pressure vessel); b) additional metallic and non-metallic materials would be exposed to high-pressure GOX; c) the sensor electrical power elements will also be exposed to high-pressure GOX.

In the event that a non-metallic is considered Category "D" as the result of high pressure GOX exposure due to a structural failure, it can be concluded that impact sensitive materials would be exposed (the transducers contain mylar and Epoxylite 6203, both having failed LOX impact tests). The non-metallic materials exposed and the amount of material for the ECS pressure transducers (LSC 360-601 and LSC 360-624) are shown in the DPS Oxidizer Table 4.2-1.

Certain other materials will be exposed to GOX pressures higher than normal operating pressures as a result of a single-point failure. These materials should be reviewed and be considered for GOX pneumatic and mechanical impact testing.

Ignition potential of all materials used in oxygen is presently verified by a standard Flash and Fire test conducted under ambient pressure conditions. The effect on ignition potential of high pressures should be evaluated by tests.

TABLE 4.4-1

LM ECS SUBSYSTEM NON-METALLIC MATERIALS LIST

Component Name and Ident. Number	Material	Application	Exposure Pressure (psia) Normal Conditions	Single Failure	Impact Data	Material Application Verification
321 Fill Coupling D/S	Kel-F-81	Poppet seal, dynamic application during fill	3000	3000	*	LCQ-330-021/Purolator test procedure No. 2095. 3000 psia oxygen
	EA-40	Thread lock, static	3000	3000		
392 High Pressure Oxygen Control Module D/S	E-617-9	"O" ring, static	3000	3000		LCQ-330-017, 1500-2200 psia oxygen blow-down; Parker System Integration Test No. 7EER5650072, 3000 psia oxygen.
	Kel-F GR 3000	Protective cover seal, static	Vacuum	3000		
	Teflon	Back-up ring Static	Vacuum	3000		
	L-449-6	"O" ring, static	Vacuum	3000		
	LS-53	"O" ring, static	Vacuum	3000		
	LS-63	"O" ring, static	Vacuum	3000		
	Viton-A	"O" ring, static	Vacuum	3000		
	L-604-7	Gasket, static	Vacuum	3000		
	Krytox-240AC	Lubricant, static	Vacuum	3000		
505 Interstage Disconnects	Teflon	Seal, static Dynamic during staging	950	1000		LCQ-330-034/Fairchild Hiller Report No.ER-318-18.900 psia oxygen
	Viton-A	"O" ring, seal, static Dynamic during staging	950	1000	*	
	Krytox-240AC	Lubricant, static/ Dynamic during staging	950 Note: LM-10 oxygen 1575	1000	*	
390 Oxygen Control Module A/S	Al. shim HS-025	Spacer	950	950		LCQ-330-061/SVHSER-4769 & 4958
	Teflon	Back-up ring, static	6.2	950		
	Viton-A	"O" ring, static	950	950		
	Kel-F-81	Thread lock, static/ Valve seat, dynamic	950	950	*	
	ZZ-R-765	"O" ring, static	950	950		
	Viton B	Valve poppet, dynamic	950	950	*	
	PLV 2000	Adhesive, static	950 EVA 6.2 cabin	950 950		
	Molykote X-15	Dry film lubricant, static	950	950		
	SE 565/Varox	"O" ring, static	950	950		
	Electrofilm 1000	Dry film lubricant, static	950	950		
	Epon 8/Cat A	Adhesive, static	950	950		
	Krytox 240 AC	Lubricant, static	950	950		

* MSC GOX Impact Data. 50 ft-lb/in^2, 2000 psia GOX, Amb Temp., 0/20 Reaction
NASA LTR PD9-L51-69-PP6-L154, Enclosure I., May 6, 1969

4.5 POTASSIUM HYDROXIDE

Spillage of KOH from the LM batteries could occur in two different forms; liquid or crystal. The liquid spillage would occur during pre-launch, while in the vacuum of space, the KOH would form KOH/water crystals.

In the event of a liquid spill of the primary batteries in the ascent or descent stage, a variety of non-metallic and metallic materials and components could possibly come in contact with the KOH. The materials most likely to come in contact with the fluid are:

- Aluminum and titanium tanks
- Anodize or alodine aluminum boxes and cold rails
- FEP/H-film wire harness
- Silicone potting and harness clamps
- Kynar/nylon solder splices and identification sleeving
- Teflon-glass anti-chafe tape
- Teflon-glass lacing cord
- Polyolefin sleeving
- Aluminized H-film thermal blanket
- Glass-nylon standoffs.

Table 4.5-1 presents KOH compatibility data for a cross section of primarily different generic type non-metallic materials. These data indicate that all the materials and/or components are compatible with the KOH liquid except the vapor-deposited aluminum on the thermal blankets. The results of the spillage on the LM-3 blankets indicated an 8-10 inch area in which the aluminum was dissolved during a 1-2 hour contact. However, the exposed layer of H-film prevented further attack to the underneath layer.

If a spill should occur during flight, the liquid on contact with the space vacuum would have the following immediate effect. The water in the KOH would start to vaporize causing a cooling effect on the liquid; (V.P. @20°C approximately 8 mm Hg) this would increase the concentration of KOH (saturated solution). This combination would cause the dihydrate ($KOH\text{-}2H_2O$) to crystallize out of solution and form a solid phase in a saturated solution. Further cooling would produce a solid mixture of dihydrates.

4.5 cont'd

It must be assumed that the crystals or particles from the solution could form in either composition. In the event that one or more touch some warm components, it is reasonable to expect that the water in the dihydrates, or saturated solution, would boil and/or vaporize, thus approaching the original KOH pellets. No compatibility problems would be anticipated with warm components and vaporizing KOH particles, since contact would be of short duration and the materials shown in Table 4.5-1 are compatible.

No compatibility problems are believed to exist during a pre-launch liquid spill except for the vacuum-deposited aluminum on the thermal blankets. In addition, any battery spill in space vacuum would form particles of either undissolved solids in saturated solutions or complete solid crystalline masses; neither of which present a compatibility problem.

TABLE 4.5-1

BATTERY MATERIALS IDENTIFICATION AND KOH COMPATIBILITY

APPLICATION	MATERIALS		REMARKS
	Ascent & Descent	Explosive Devices	
Cell Case	ABS	Epoxy-Glass (G-10)	In contact with KOH-compatible
Battery Case	Nickel Plated Magnesium (AZ31B)	Gray Velvet coated Epoxy-Glass (G-10)	Nickel resistant to KOH spillage - Paint attached by KOH
Separators	Cellophane	Cellophane	In contact with KOH - compatible
Separators	Nylon	-	In contact with KOH - compatible
Separators	Rayon	-	In contact with KOH - compatible
Cell Relief Valve	ABS, Neoprene	Neoprene	In contact with KOH - compatible
Case Relief Valve	Stainless Steel	Stainless Steel, SR-634-70 Rubber	Partial contact with KOH - compatible
Case Seal	Nitrile Rubber	SR-634-70 Rubber	Partial contact with KOH - compatible during relief or venting
Intercell connections	RTV-731	-	Partial contact with KOH - compatible
Cell Terminals	RTV-601	-	Partial contact with KOH - compatible
+ Plate	Silver	Silver	In contact with KOH - compatible
- Plate	Zinc	Zinc	In contact with KOH - compatible

TABLE 4.5-1 (cont'd)

BATTERY MATERIALS IDENTIFICATION AND KOH COMPATIBILITY

APPLICATION	GENERIC MATERIALS EXPOSED TO KOH SPILLAGE	REMARKS
IM-3 Thermal Blanket	Vapor deposited Aluminized H-film	Aluminum (1000-2000 Angstroms) dissolved but H-film was resistant
	Aluminum	Mild Etch
	Titanium	No chemical attack
	Teflon	*Compatible
	Kynar	*Compatible
	Silicones	*Compatible
	Epoxies	*Compatible
	Polyolefin	**Compatible

* Plastic Properties Chart, Modern Plastics Ency, 1968-1969

** Rayclad Tubes Inc.

4.6 TYPES OF EXTERNAL LM MATERIALS DAMAGED BY OXIDIZER TANK CONTENTS

LM materials external to the propulsion subsystems were not selected for compatibility with the propellant oxidizer (N_2O_4). However, in the absence of atmospheric moisture and in the presence of the space vacuum, available compatibility reports indicate the primary structural materials, aluminmum, stainless steel, titanium, nickel alloys, and low alloy steel are compatible. Many non-metallic materials, however, are expected to have a very limited life capability dependent on the N_2O_4 concentration and temperature on the part.

Table 4.6-1 lists the primary exposed external LM materials including usage, time to failure in liquid oxidizer, temperature at which the failure occurs, and stage (ascent-descent) location. Vapor phase N_2O_4 exposure data on non-metallic materials is limited and not available for most materials listed in the table. Materials listed in the table would probably be exposed to vapor in lieu of worst case liquid exposure, and the time to failure in an actual mission would be considerably longer than that given in the Table 4.6-1. Materials listed in the table which fail in less than 24 hours, or for which no data exists, have been evaluated as follows:

- o Materials listed below are used in applications for which some N_2O_4 degradation should not prevent an abort:
  - Epon 934 for wiring and instrumentation bonding
  - Mystic 7402 tape tubing wrap
  - Kingsley aluminum ID tape
  - Marking ink
  - Corfil 615 edging compound
  - Velvet 400 series paint
  - DC 1410 silicone sleeve anti chafe
  - Dodge fiber TFE/Glass tape
  - Teflon 62 3m tape spacer
  - Torque strip paint
- o Material listed below could be critical to an abort if exposed to N_2O_4.
  - Silicone cable clamp wire support - degradation could cause wire chafing and subsequent shorting of wiring.

4.6 cont'd

- H-film pressure sensitive tape - degradation could cause blanket decay and loss of thermal properties.
- Epoxy fiberglass laminate standoffs - failure could cause loss of the thermal insulation and micrometeoroid shields.
- Nylon tie wraps and bases - failures could cause excessive strain on the wire bundles and possible shorting.
- Nylon Velcro - failure could cause insulation loss.
- Kynar/Nylon solder and crimp wire splices - failure of the nylon could cause circuit failure.
- EC 1663 potting - degradation could cause shorting conditions.
- Epon 919 cabin pressure sealant - failure would cause cabin pressure loss.
- Nylon/copper terminal lugs - failure could cause loss of grounding.

The list of materials was compiled from photographs and vehicle inspection rather than a rigorous drawing review and should not be considered conclusive. If N_2O_4 compatibility of exterior surfaces were to become a program requirement an additional review and subsequent testing recommendations should be considered. It should be emphasized that a massive spill could be disastrous due to materials failures. The greatest concern with a spill would be with a relatively small leak which may go undetected for an extended period of time.

TABLE 4.6-1

EFFECT OF LIQUID N_2O_4 EXPOSURE ON EXTERNAL LM MATERIALS

LM EXTERIOR MATERIALS	USE	OXID. EFFECTS TIME TO FAILURE*	°F TEMP	DOCUMENT	STAGE ASCENT (A) DESCENT (D)
H Film/Aluminum	Super Insulation	7 Days	70	4	A/D
Epon/Fiberglass Laminate	Stand-Offs	1 Hour	60	1	A
Epon 919	Cabin Sealant	24 Hours	75	1	A
Epon 934	Bond Wiring & Instrumentation	24 Hours	75	1	A/D
Kynar/Nylon Solder Splices	Wire Splices	72 Hours	85	1	A/D
Kynar/Nylon Crimp Splices	Wire Splices	72 Hours	80	1	A/D
Kynar/Nylon End Caps	Wire Caps	72 Hours	85	1	A/D
TFE/Polyimide (H Film)	Wire Insulation	Satisfactory 8 hrs.		5	A/D
TFE Alpha Braided Cable	Wire Chafe	Satisfactory	160	2	A/D
Silicone Cable Clamp (NE 4661)	Wire Support	1 Hour	80	1	A/D
Mystic 7402 Tape	Tubing Wrap	1 Hour	80	1	A/D
Kingsley Aluminum ID Tape	Information Labels	ND			A/D
Kynar ID Sleeves	Identification Sleeve	72 Hours	85	1	A/D
Marking Inks (Black-Red)	Marking	24 Hours (Bleaches)	80	1	A/D
Corfil - 615	Edging Compound	NR	60	1	A

TABLE 4.6-1 (cont'd)

LM EXTERIOR MATERIALS	USE	OXID. EFFECTS TIME TO FAILURE*	$^{\circ}$F TEMP	DOCUMENT	STAGE ASCENT (A) DESCENT (D)
TFE Glass	Lacing Tape	Satisfactory	80	2	A/D
Velvet 400 Series	Paint	Bleach 1 Hour	80	1	A/D
EC-1663	Potting Compound	Unsatisfactory	75	1	A/D
White Teflon Sheet	Spacers	Satisfactory	75	2	A/D
Clear FEP (Teflon) Sheet	Spacers	Satisfactory	160	2	A/D
DC 1410 Silicone Sleeve	Anti Chafe	(Dissolves) 24 Hours	80	-	A/D
Nylon	Tie Wraps & Bases	Disintegrates (24 Hours)	60	1	A/D
Dodge Fiber TFE/Glass Type	Anti Chafe	ND	-	-	A/D
Dodge Fiber Unsintered TFE/Glass	Connector Protection	NO	-	-	A/D
Nylon/Copper Terminal - Lugs	Insulation for Grounds	24 Hours	65	1	A/D
Black Shrink Fit Polyolefin	Anti Chafe Insulation	Cracks 7 days	75	1	A

TABLE 4.6-1 (cont'd)

LM EXTERIOR MATERIALS	USE	OXID. EFFECTS TIME TO FAILURE*	°F TEMP	DOCUMENT	STAGE ASCENT (A) DESCENT (D)
Teflon Jacketed Wire (Blue, Green, Grey, Black, White)	Wire Insulation	Satisfactory	60	2	A/D
Teflon 62 3M Tape	Wire Bundle Clamp Spacer	24 Hours	80	1	A/D
Teflon Plumbing Clamps	Attach Plumbing Lines to Structure	Satisfactory	75	2	A/D
H Film Pressure Sensitive Tape	Closure on H-Film Super Insulation	24 Hours	80	1	A/D
Aluminum 6061	H_2O Tanks & Plumbing	Satisfactory	150	2	A/D
Inconel 718	A/S GOX Tanks	NR	65	2	A
Zinc Chromate	Primer - Anti Corrosion	ND	-	-	A/D
Nylon/Velcro (Hook & Pile)	Attach super insulating blankets to structure	24 Hours (60°)	80	1	A/D

TABLE 4.6-1 (cont'd)

LM EXTERIOR MATERIALS	USE	OXID. EFFECTS TIME TO FAILURE*	°F TEMP	DOCUMENT	STAGE ASCENT (A) DESCENT (D)
Red Torque Stripe Paint	Q.C. Seal	Bleaches 1 hour	80	1	A/D
Butyl Heat Shrink Tubing	Anti Chafe	Incompatible	60	1	D
D6-AC Steel	D/S GOX Tank	Satisfactory	140	2	D
Aluminum - 7075, 7079	D/S Structure	Satisfactory	150	2	D
Aluminum - 2219, 7075, 2024, 7079	A/S Structure	Satisfactory	60	2	A
Nylon	Battery Terminal Insulator	Unsatisfactory	60	1	A/D

Documents Referenced:

1. Compatiblity of Plastics With Liquid Propellants, Fuel and Oxidizers, Plastec Report No. 25.
2. Compatibility of Materials with Rocket Propellants and Oxidizers, DMIC Memo 201, 29 January 1965.
3. Compatibility of Materials in Storable Propellants for XSM-68B and SM 68B Third Progress Report ME. Report #22, 10 November 1960, Martin Denver.
4. LMO 510-155, 24 March 1969 Status Report: Concentrated Propellant Vapor Test on LM Thermal Blankets.
5. CTE 390-006 Wiring Qualification - 8 hour fuel and oxidizer soak.

*Where data was not available on the specific material listed, oxidizer effects were based on material in the same generic family.

4.7 SYSTEM PRESSURE RISE THROUGH COMBUSTION OF NON-METALLICS

An analysis has been made to estimate the system pressure rise as a result of a structural single-point failure and combustion of the non-metallics exposed as a result of that failure. The following components were included in this analysis: temperature transducers, absolute pressure transducers, RCS solenoid valve, Propellant Quantity Gauging System, and Propellant Level Detector.

- LSC 360-605 - Temperature Transducer
  - Assumption - APS Ullage Vol. $1.0 ft^3$
    Expected Max. ΔP = 17psi
  - Assumption - DPS Ullage Vol. $0.94 ft^3$
    Expected Max. ΔP = 18 psi
- LSC 360-624-XXX-2-Absolute Pressure Transducer
  - Assumption - DPS Ullage Vol. $0.94 ft^3$
    Expected Max. ΔP = 6 psi
  - Assumption-ECS GOX Vol. $3 ft^3$
    Expected Max. ΔP = 2 psi
- LSC 360-601 Absolute Pressure Transducer
  - Negligible pressure rise APS, DPS, RCS and ECS
- LSC 360-624-1-31 Absolute Pressure Transducer
  - Assumption - APS Ullage Vol. $1.0 ft^3$
    Expected Max. ΔP = 6 psi
- LSC 310-403 Solenoid Valve
  - Assumption - RCS Ullage Volume 125 in^3
    Expected Max. ΔP=0.5 psi
- LSC 270-00009 Propellant Quantity Gauging System
  - Assumption - DPS Ullage Vol. $0.94 ft^3$
    Estimated Max. ΔP = 79 psi for Rulon A plus Teflon
    17 psi for RTV - 20
    175 psi for Stycast 1090
- LSC 270-801 Propellant Level Detector
  - Assumption - APS Ullage Vol. $1.0 ft^3$
    Estimated Max. ΔP = 36 Psi

All of the pressure increases are expected to be within system capability with the exception of the Propellant Quantity Gauging System (PQGS). The RTV-20 and Epoxy require a structural metal case failure to expose these materials to the

propellant whereas the Rulon A plus Teflon are exposed to the propellant at all times. Combined pressure rises for all the materials in the PQGS coupled with tank operating pressure of 245 psi would be enough to exceed tank design ultimate of 405 psi. However, with the possible exception of an explosive rise in pressure, the tank relief system would limit pressure rise to 275 psi. No methods of obtaining such an explosive rise are known.

The pressure rise from the PLD may be sufficient to fail the burst disc in the APS. Normal operating pressure of this system is 190 psi with the relief system opening at 226-250 psi.

Pressure rise from the failure and combustion of DPS temperature transducer materials may be sufficient to fail the burst disc in the DPS. Normal operating pressure of this system is 245 psi, with the relief system opening at 260-275 psi.

All other items resulted in single pressure rises low enough to be within normal system capabilities.

An additional analysis has been made to estimate the pressure rise in transducer chambers as a result of combustion of the non-metallics located in the reference chamber. For the purposes of this analysis it is assumed that there is no venting of the gasses overboard through electrical wiring potting or venting back into propulsion or GOX tank cavities. The calculated pressure rise is considered to be a minimum since the reference chambers also contain metallic items such as wiring which occupy varying amounts of the assumed reference chamber volume.

- LSC 360-605 - Temperature Transducer
  -Assumption 0.5 in^3 Ref. Chamber Volume
  Expected ΔP = 59,000 psi
- LSC 360-624-XXX-2 and -1-31 Absolute Pressure Transducer
  -Assumption 0.18 in^3 Ref. Chamber Volume
  Expected ΔP = 55,000 psi
- LSC 270-00009 Propellant Quantity Gauging System
  -Assumption 14 in^3 Ref. Chamber Volume
  Expected ΔP = 1970 psi for RTV-20
  20300 psi for Stycast 1090
- LSC 270-801 Propellant Level Detector

4.7 cont'd

-Assumption 1 in^3 Ref. Chamber Volume

Expected $\Delta P = 62{,}000$ psi

- o LSC 310-403 Solenoid Valve

-Assumption 0.67 in^3 Ref. Chamber Volume

Expected $\Delta P = 95$ psi

4.8 REFERENCES

1. AFBSD-TR-62-2 Revision A. Titan II Storable Propellant Handbook; Bell Aerospace Corporation, March 1962.

2. ASD-TR-61-324 "Mechanically Induced Reaction of Organic Materials in Missile Oxidizers", The Martin Company, October 1961.

3. CR-64-88 Technical Operating Report "Propellants Compatibility Report", The Martin Company, Denver, Colorado Contract AF04(647)-57676, November 1964.

4. DMIC Memorandum 201 Compatibility of Materials with Rocket Propellants and Oxidizers Defense Metals Information Center, Battelle Memorial Institute, Columbus, Ohio 43201.

5. Materials Engineering Report No. 63-497, Aerojet General Corporation Liquid Rocket Plant, Sacramento, California, October 1963.

6. Report No. LRP 198 Second Edition Storable Liquid Propellants Nitrogen Tetroxide/Aerozine 50 Aerojet General Corporation Liquid Rocket Plant, Sacramento, California, June 1962.

7. RPL-TDR-64-103 Space Vehicle Propulsion Compartment Fire Hazard Investigation Volume I Air Force Rocket Propulsion Laboratory Research and Technology Division; Air Force Systems Command Edwards AFB California July 1964.

8. MIL-TDR-64-107 Part IV Elastomeric and Compliant Materials for Liquid Rocket Fuel and Oxidizer Applications Thiokol Chemical Corporation Reaction Motors Division April 1, 1967.

9. LMO-254-244 White Sands Test Facility Propellant Exposure History Grumman Aerospace Corporation Memorandum 1 May, 1969.

10. TR-P-10077 Revision 1 and 2. Technical Report - Parker Seal Company.

11. Technical Data Report - BC 0365-045 Evaluation of Rulon Covered Teflon Bumpers For The LM Descent Stage Propellant Tank Antislosh Baffle 9 May, 1966.

12. TWX-303-292-2370 From the Martin Company, Denver, Colorado to Aerojet Sacramento, California, Liquid Rocket Plant, P.O.Box 1947. 6 January, 1965.

4.9 DISCUSSION

MSC nonmetallic materials control for flammability and toxicity is presently limited to the crew bay and the oxygen system. It would be desirable to implement an overall MSC criteria and control that would insure that all materials used throughout the spacecraft were evaluated uniformly for all physical and functional requirements.

5. BURST TEST HISTORY

5.1 SUMMARY

This section presents a description of all available burst test data for the LM pressure vessels. A discussion is also presented on the LM batteries and pressure/temperature transducers that interface with the LM pressure vessels.

For the most part, the only available burst data is for hydrostatic failures. During development and qualification testing, it is normal practice to conduct burst tests hydrostatically instead of pneumatically, even though the tank may ultimately be used pneumatically. The prime consideration of the burst test is to demonstrate that design burst pressure has been reached or exceeded; this can be demonstrated either pneumatically or hydrostatically. Since there is always the possibility that a tank may fail prematurely, it is desirable to conduct burst tests hydrostatically to facilitate a post-test failure analysis if required. Secondary considerations are the facility limitations and danger in conducting pneumatic failure tests.

Some pneumatic tank ruptures have been experienced during the LM program. In all instances, the failures were catastrophic in nature, with extreme fragmentation of the pressure vessels.

Table 5.1-1 summarizes the burst test data for the LM pressure vessels. For reference purposes, the overall certification test requirements for the pressure vessels and associated components are summarized in Table 5.1-2.

In general, it is believed that if any of the LM pressure vessels were to fail in flight at, or greater than, design burst pressure, the tank would explode and fragment. Less catastrophic failures could be expected if any of the tanks were to fail prematurely at, or near, normal operating pressure. Section 6 presents a discussion of the anticipated failure modes and the resultant damage potential.

TABLE 5.1-1 PRESSURE VESSEL BURST HISTORY

PRESSURE VESSEL	DESIGN BURST		ACTUAL BURST		HYDRO or PNEUM	ADDITIONAL TEST DATA INFORMATION
	PRESS. PSIG	TEMP °F	PRESS. PSIG	TEMP °F		
DPS Propellant Tanks (Oxid. & Fuel)	405	AMB	DVT - 415 QUAL - 40[illegible] COMPAT- 440	AMB AMB 97 to 110	H H H	o Cycle test to failure; cycle pressure was 15 to 310 PSIG; H_2O filled tank ruptured 3,384th cycle; min. req. was 400 cycles. 0-270 PSIG. o Tank failure at 180 PSIG, pneumatically caused by aluminum cover failure. Changed to Titanium cover for correction o Tank failure during proof at 267 PSIG. Failure due to a localized microstructure abnormality. (See para. 5.2.1 for additional discussion)
DPS SHe Tank Internal Heat Exchanger	3420	140°R	3512 3425	140°R	P P	Tank ruptured at 3,512 PSIG and burst at 3,728 PSIG. AiResearch report QTP 900152 Rev. 1 Tank Serial No. 12 3/3/67
DPS AMB He Start Tank	2625	100	3100	64	H	GAC test anomoly on LM-5 at 1605 PSIG; temperature was 173°F. Max allowable temperature is 140°F. Acceptable Ref. FGAE 4250
APS Propellant Tanks (Oxid. & Fuel)	375	AMB	QUAL - 452 Updated tank QUAL-494,478 COMPAT-558,512 DVT - 465 COMPAT-245 ±5	AMB AMB 100 AMB 103	H H H H H	Tank failed after 47 hours of test at 245 ±5 PSIG during compatibility testing of N_2O_4. The failure resulted from stress corrosion (See para. 5.3.1 for additional discussion)

TABLE 5.1-1 (Continued)

PRESSURE VESSEL	DESIGN BURST PRESS. PSIG	DESIGN BURST TEMP °F	ACTUAL BURST PRESS. PSIG	ACTUAL BURST TEMP °F	HYDRO or PNEUM	ADDITIONAL TEST DATA INFORMATION
APS He Tank	5250	160	5,740 5,500	160 160	H H	
RCS Propellant Tanks (Oxid. & Fuel)	375	100	QUAL, Oxid 767, 775 QUAL, Fuel 589, 622	70 70	H H	
RCS He Tanks	5250	130	5,700 5,800	130 130	H H	
ECS D/S Oxygen Tank	4500	160	QUAL - 5400, 5350 DFT - 5400 Overstress - 5200, 5500 Prod. Accept 3000	66 66 66, 74	H H H H	In production acceptance test, a tank failed at 3,000 PSIG (FA 1001); failure was attributed to a crack in the tank material. Stress corrosion created by immersion in H_2O during testing and inspection methods had not detected crack. Inspection methods revised and H_2O immersion removed from test procedure (Ref. para. 5.5.1 for additional discussion)
ECS A/S Oxygen Tanks	1500	160	QUAL - 2010 - 2070 DFT - 2180 - 2150	75 75 160 75	H H H H	

TABLE 5.1-1 (Continued)

PRESSURE VESSEL	DESIGN BURST		ACTUAL BURST		HYDRO or PNEUM	ADDITIONAL TEST DATA INFORMATION
	PRESS. PSIG	TEMP °F	PRESS. PSIG	TEMP °F		
ECS D/S Water Tanks	96	70	DFT - 262	70	H	
ECS A/S Water Tanks	96	70	DFT - 314	75	H	
EPS D/S & A/S Primary Battery	10.7	20-145				

Table 5.1-2 Certification Test Requirements Summary

DPS

Cert Test Environments

CTR	ITEM	VENDOR RPT	TEST START	TEST COMP	CTE APRVD	LM	Ultra Hi-Vacuum 10-9	Thermal Vacuum 10-5	Vibration	Shock	Oxygen	Humidity - Temp.	Sea Air Humidity	Corrosive Contam.	Temperature	Acceleration	EMI	Fluid Compatibility	Salt Fog	Vibration/Temp.	Burst Pressure	ADDED TESTS
270-001 See 270-035 -083	D/S Prop. Tank Assy & Cover LSC 230 4-51, -53, -55, -57	EDR 4678 & EDR 4944, Vol. I., Allison Div., GMC	6-66	11-1-67	7-28-67	1 only	TANK:		X	X						X						Cycling, Creep, and Proof Pressure
							COVERS														X	Proof Pressure Cycling & Creep
270-030	S/C Helium Tank LSC 270-321-53-1	Airesearch 66-1484 & 67-1649 & AE-10241-MR & AE-10287-R.	8-12-66	3-3-67	3-26-68	LM-3 & Sub			X	X						X					X	Cycling & Thermal Testing.
310-003	RCS Propellant Latch Valve LSC 310-403-305	Parker # QTR 5640014 Rev. A and GAC ZTR 310-58	3-66	10-20-68	4-7-69	LM-4 & Sub.			X	X					X		X	X				Press Drop Press Cycling Proof Press Insulation Resistance
270-005	Prop. Quantity Gaging Section LSC 270-00009	Trans-Sonics A123325, Vols. I, II & III	9-28-66	6-19-67	1-23-67	1 & Sub.			X	X								X			X	Dielectric, Insulation & Insulation Resistance, Endurance & Loading Cycle.
270-116	PQGS Probe Assembly LSC 270-00009	Unknown	4-27-70	4-29-70	-------	8 & Sub.			X													Dielectric, Isolation & Insulation Resistance & Flow Test.
270-020	Valve, Explosive LSC 270-819	ER 1200-24 OGDEN Lab Rpt. 69138	4-28-66	9-19-66	10-5-67 11-3-69	1 & Sub. 5 & Sub.		X	X	X			X			X					X	Sand & Dust

Table 5.1-2 (continued)

DPS

Cert Test Environments

CIR	ITEM	VENDOR RPT	TEST START	TEST COMP	CTE APRVD	LM	Ultra Hi-Vacuum 10-9	Thermal Vacuum 10-5	Vibration	Shock	Oxygen	Humidity - Temp.	Sea Air Humidity	Corrosive Contam.	Temperature	Acceleration	EMI	Fluid Compatibility	Salt Fog	Vibration/Temp.	Burst Pressure	ADDED TESTS
270-035	D/S Prop. Tank Assy & Cover LSC 280-4-?7, -?9, -71 & -73	EDR 4?78 & EDR 4944, Vol.I & II, Allison Div. GMC	11-?-?7	11-?-[illegible]	2-20-?8	LM-? & Sub			QUALED BY SIMILARITY TO 270-001)													
270-083	D/S Prop. Tank Cover + Interface Plumbing LDW ?FO?155?-1?, -1?	LTR 905-?1001, GAC	5-?-?8	5-14-??	5-2?-?9	LM-3 thru LM-?			X												X	Proof Pressure and Cycling.
270-088	Des?. Prop. He Stor. Tank LSC 270-825-1	Wyle Labs 49607	3-7-?8	3-1?-??	8-?-?8	LM-? & Sub				X												

Table 5.1-2 (continued)

APS

CTR	ITEM	VENDOR RPT	TEST START	TEST COMP	CTE APRVD	LM	Ultra Hi-Vacuum 10-9	Thermal Vacuum 10-5	Vibration	Shock	Oxygen	Humidity - Temp.	Sea Air Humidity	Corrosive Contam.	Temperature	Acceleration	EMI	Fluid Compatibility	Salt Fog	Vibration/Temp.	Burst Pressure	ADDED TESTS
270-004	Asc. Tank LSC 280-7-57-3 & -58-3	ACC 1-4081-01-5.3.2-7.0, -7.1, -7.2, Vol. I, -7-2 Vol. II, -7.3, -7.4 & -3.34	4-7-66	11-11-66	2-28-67	1 & Sub.				X						X					X	Cycling & Creep
270-024	A/S He Tanks LSC 270-711-1-1	United Aero Test Labs 21032	5-66	4-30-66	2-28-67 7-28-69	1 & Sub. 8 & Sub.		X	X							X			X		X	
270-020	Valve, Explosive LSC 270-819	ER 1200-24 OGDEN Lab Rpt 60132	4-25-66	9-19-66	10-5-67 11-3-69	1 & Sub 5 & Sub		X	X	X			X			X					X	Sand & Dust
270-025	Detector, Level Proj. LSC 270-831-14 (Ox) LSC 270-8 1-13 (Fuel)	ER 2146-100 Liquidometer Aerospace Div Simmonds Precision Products, Inc	6-3-66	9-26-66	3-24-67	1 & Sub				X			X		X		X	X			X	Voltage Variation, Power Consumption, Dielectric Strength, Insul. Resistance, Leakage, Fungus Isolation Resistance.
360-052	Absolute Pressure Transducer LSC 360-601-203-3	Dynasciences #QTR 630037-23	4-11-69	10-10-69	1-16-70	7 & Sub		X		X	X		X		X	X	X	X		X		
									All Environments (Except Fluid Compatibility) By Similarity to 360-048.													

Table 5.1-2 (continued)

APS

Cert Test Environments

CTR	ITEM	VENDOR RPT	TEST START	TEST COMP	CTE APRVD	LM	Ultra Hi-Vacuum 10-9	Thermal Vacuum 10-5	Vibration	Shock	Oxygen	Humidity - Temp.	Sea Air Humidity	Corrosive Contam.	Temperature	Acceleration	EMI	Fluid Compatibility	Salt Fog	Vibration/Temp.	Burst Pressure	ADDED TESTS
270-007	Oxidizer Couplings LSC 270-702	J. C. Carter Co. 4058-Q, Rev. B	9-27-65	12-29-65	1-24-67	1 & Sub.															X	Pressure, Functional Leakage
270-106		14R6870, 15R6870, 16R6870, 17R6870.	4-2-68	4-10-68	10-22-68	3 & Sub.															X	Disengaged Slippage, Refuel Direction, Defuel Direction 100 Endur. Cycles each.
270-009	Oxidizer Couplings	J. C. Carter Co. 4058-Q, Rev. B	9-27-65	12-29-65	2-28-67	1 & Sub.			X	X						X					X	Pressure Drop
270-107		3534-1 Amend. 1 & 2; CR6761 & 8R6761	10-18-67	10-26-67	10-22-67	3 & Sub.				COMMON USAGE WITH NORTH AMERICAN												
270-093	Asc. Prop. Tank Assy Weldment LSC 280-70-5	AGC-TR-51420-2 Vol. I & II & Amend No. 1 -TR 51421-2 -TR 51422-2 Vol. I & II -TR 51425-2 & Amend No. 1 -TR 51440-3 Vol. I & II & Amend No. 1 -TR 51441-3 -TR 51421-3 -TR 51422-3 Vol. I & II -TR 51425-3	7-9-68	5-22-69	11-3-69	LM-6 & Sub.			X							X					X	Crogenic Proof Press. & FITH Test

RCS

Cert Test Environments

CTR	ITEM	VENDOR RPT	TEST START	TEST COMP	CTE APRVD	LM	Ultra Hi-Vacuum 10^{-9}	Thermal Vacuum 10^{-5}	Vibration	Shock	Oxygen	Humidity - Temp.	Sea Air Humidity	Corrosive Contam.	Temperature	Acceleration	EMI	Fluid Compatibility	Salt Fog	Vibration/Temp.	Burst Pressure	ADDED TESTS
310-001	Tank He Lt. Wt. LSC 310-301	Airite Div. Sargent Industries United Aerotert Labs. 21237	-[illegible]3-	[illegible]	[illegible]-21-	[illegible] Sub.			X	X						X					X	Pressure Cycling & Creep
310-004	RCS Prop. Tanks LSC 310-405-[illegible] & -12	Bell Aerosystems # 8339-928023	5-13-[illegible]	11-15-[illegible]	10-12-67	1 & Sub.			X	X					X	X					X	Proof Pressure and Cycling, Shock Test
360-052	Absolute Pressure Transducer LSC 360-[illegible]01-203-3	Dynasciences #QTR 630037-23	9-11-69	10-10-[illegible]9	1-1[illegible]-70	7 & Sub.		X		X	X		X		X	X	X	X		X		
									All Environments (Except Fluid Compatibility) By Similarity to 3[illegible]0-04[illegible].													
310-003	RCS Propellant Latch Latch Valve LSC 310-403, 103, -204, -303	Parker # QTR 5640014 Rev A and GAC LTR 310-58	3-[illegible]	10-[illegible]-[illegible]	4-7-69	3 & Sub.			X	X					X		X	X				Pressure Drop Pressure Cycling Proof Pressure Insulation Resistance
310-012	RCS Engine LSC 310-130-13-1 (NAA Dwg #ME 901-0004)	Marquardt #A1057 and	8-1 -[illegible]5	1[illegible]-31-[illegible]5	[illegible]-21-[illegible]7	1 & Sub.			X			X							X			
310-033		(△ Qual) Marquardt #L1041	11-23-[illegible]	1-20-[illegible]7	10-5-[illegible]7	1 & Sub	Direct Coil and Other Tests Utilizing Helium Saturated A-50 Fuel, and Helium Saturated N_2O_4 with Nitric Oxide Content Between 0.[illegible] - 0.9% by Weight as Oxidizer															

Table 5.1-2 (continued)

ECS

DESC. O_2

Cert Test Environments

CTR	ITEM	VENDOR RPT	TEST START	TEST COMP	CTE APRVD	LM	Ultra Hi-Vacuum 10-9	Thermal Vacuum 10-5	Vibration	Shock	Oxygen	Humidity - Temp.	Sea Air Humidity	Corrosive Contam.	Temperature	Acceleration	EMI	Fluid Compatibility	Salt Fog	Vibration/Temp.	Burst Pressure	ADDED TESTS
330-020	Desc. Ox Tank (Gaseous) LSC 320-329-3-1	Wyle Labs. Report 47319	9-9-66	11-21-66	4-28-67 7-3-68	2 & Sub. 6 & Sub.			X	X	X	X				X			X		X	Creep, Pressure Cycling and Leakage.
360-048	Descent O_2 Pressure Transducer LSC 360-601-209-3	Whittaker Report #QTR 630037	7-1-68	9-9-68	2-19-69	LM-5 & Sub.		X		X	X		X		X	X	X			X		Insulation Resistance.

Table 5.1-2 (continued)

ECS

ASC. O_2

CTR	ITEM	VENDOR RPT	TEST START	TEST COMP	CTE APRVD	LM	Ultra Hi-Vacuum 10^{-9}	Thermal Vacuum 10^{-5}	Vibration	Shock	Oxygen	Humidity - Temp.	Sea Air Humidity	Corrosive Contam.	Temperature	Acceleration	EMI	Fluid Compatibility	Salt Fog	Vibration/Temp.	Burst Pressure	ADDED TESTS
							Cert Test Environments															
330-039	Asc. Ox. Tank (Gaseous) LSC 330-318-1-1	Wyle Labs. Report 47093	4-27-66	6-28-66	6-6-67	1 & Sub.			X	X					X	X					X	Pressure Cycling and Creep
360-039	Ascent # 1 O_2 Pressure Transducer LSC 360-601-201-2 Ascent # 2 O_2 Pressure Transducer LSC 360-601-201-2	Pace-Wiancko (Whittaker) # 690016	8-1-67	8-31-67	12-27-67	LM-1 & Sub.		X			X		X		X					X		Thermal Cycling Insulation Resistance.
360-041	O_2 Manifold Pressure Transducer LSC 360-624-211-2	EOS # QTR 00019	8-1-67	9-2-67	4-8-68	LM-1 & Sub.		X			X		X		X					X		Thermal Cycling Insulation Resistance.

Table 5.1-[illegible] (continued)

ECS

DESC. H_2O

Cert Test Environments

CTR	ITEM	VENDOR RPT	TEST START	TEST COMP	CTE APRVD	LM	Ultra Hi-Vacuum 10-9	Thermal Vacuum 10-5	Vibration	Shock	Oxygen	Humidity - Temp.	Sea Air Humidity	Corrosive Contam.	Temperature	Acceleration	EMI	Fluid Compatibility	Salt Fog	Vibration/Temp.	Burst Pressure	ADDED TESTS
330-[illegible]1	Des. H_2O Tar LSC 330-404-3-2	Ham. Std. SVHSER 430 & 4346 & Rev. for Each & 4706	9-66	1-67	2-9-68 7-3-68	1 & 2 only CA 1 & Sub.			X	X		X				X		X		X	X	

Table 5.1-2 (continued)

FCS

ASC. H_2O

Cert Test Environments

CTR	ITEM	VENDOR RPT	TEST START	TEST COMP	CTE APRVD	LM	Ultra Hi-Vacuum 10-9	Thermal Vacuum 10-5	Vibration	Shock	Oxygen	Humidity - Temp.	Sea Air Humidity	Corrosive Contm.	Temperature	Acceleration	EMI	Fluid Compatibility	Salt Fog	Vibration/Temp.	Burst Pressure	ADDED TESTS
330-032	Asc. H_2O Tank LSC 330-409-3-4	Ham. Std. SVHSER 4302 & 4345 & Rev. A for each & 4707	9-66	1-67	2-9-68 7-3-68	1 & 2 only CA 1 & Sub.			X	X		X				X		X		X	X	

[illegible] (Continued)

EPS

CTR	ITEM	VENDOR RPT	TEST START	TEST COMP	CTE APRVD	LM	Ultra Hi-Vacuum 10^{-9}	Thermal Vacuum 10^{-5}	Vibration	Shock	Oxygen	Humidity - Temp.	Sea Air Humidity	Corrosive Contam.	Temperature	Acceleration	EMI	Fluid Compatibility	Salt Fog	Vibration Temp.	Burst Pressure	ADDED TESTS
390-008	Battery, Ascent Stage LSC 390-21000	Eagle-Picher Qual 3RA	2-1-[illegible]7	3-[illegible]7-[illegible]7	5-9-[illegible]	1 & Sub.		X		X			X		X	X				X		
390-009	Battery, Descent Stage LSC 390-[illegible]000	Eagle-Picher Qual 3RD & Supplements 1 & 2	2-22-[illegible]7	3-27-[illegible]7	5-9-[illegible]8	1 & Sub.		X		X					X	X				X		
320-007	Battery, Pyro LDW 320-301	GAC LTR 922-13001	10-11-[illegible]	11-15-[illegible]	11-29-[illegible]7	1 & Sub.		X	X			X										

5.2 DESCENT PROPULSION SUBSYSTEM

5.2.1 Descent Propellant Tank

Three descent propellant tanks were hydrostatically tested to burst; the test results are summarized in Table 5.1-1.

A tank was subjected to 44-day compatibility testing with N_2O_4 per MIL-P-26539A. When filled with this fluid, the conditions were 265 psig internal pressure at a temperature of 97°F to 110°F. Following this exposure for 44 days, the tank was given one proof cycle to 360 psig with water followed by a burst test. The burst pressure was 440 psig and failure occurred in the lower dome.

An additional tank was cycled to failure. It passed a proof test at 360 psig (water) and was then subjected to pressure cycles from 15 to 310 psig filled with water. The tank ruptured during the 3384th cycle. Failure originated in the upper dome and propagated through the cylindrical section. The temperature during the test was maintained between 95°F and 100°F. Minimum mission requirements for this tank are 400 cycles from 0 to 270 psig.

Tank 55 (S/N G-029), was failed catastrophically during a helium leak test (Reference Figures 5.2-1 through 5.2-4) on 23 August 1966 . Pressure in the tank assembly was being increased for the high pressure (270 psig) leak test. A pressure of 180 psig had just been recorded when failure occurred. The failure occurred while the tank assembly was inside a helium collection chamber. The tank shattered into many pieces and the helium collection chamber and adjacent equipment were severely damaged. The failure investigation disclosed that the failure originated in the 2014CT651 aluminum cover. The cause of failure was stress corrosion, possibly resulting from a 360 psig proof test with demineralized water which the cover received thirteen days earlier. The corrective action was to substitute titanium covers for the aluminum. No tanks with aluminum covers have been, or are, used on flight vehicles. No failures have occurred with titanium covers.

5.2.1 cont'd

Tank 31, (S/N G-009), failed catastrophically during a hydrostatic proof test at 267 psig; approximately 74% of the 360 psig proof pressure. The fracture, which originated in the upper dome split the tank meridianally along a path approximately 4 inches from the tank axis. A thorough metallurgical investigation revealed that the failure was due to a localized microstructure abnormality consisting of embrittled massive alpha phase in the upper dome. The true source of this massive alpha structure is unknown, but it was present in the forging during the forging operation. Alpha inclusions of this sort cannot be detected by radiographic or ultrasonic inspection but must be screen by the tank proof pressure test.

5.2.2 Descent SHe Tank

One SHe tank was pneumatically tested to actual burst pressure; the test results are presented in Table 5.1-1. The results of a SHe tank burst can be seen in Figures 5.2-5 through 5.2-9.

In addition to the SHe tank burst test, one inner shell was pneumatically tested to burst during DVT testing. The shell burst at a pressure of 3910 psig at 138°R. During the burst of the SHe tank, the primary and secondary burst discs ruptured at 1978 psig. Helium temperature at time of rupture was 140°R.

Data indicates that seven SHe tanks have imploded. Four failures were attributed to handling damage. Three units failed during external proof pressure screening tests. The screening test prevents marginal units from being installed on a flight vehicle. These test reults are summarized in Table 5.2-1.

5.2.3 Ambient Helium Start Tank

One DPS ambient helium start tank was hydrostatically tested to burst. Test results are summarized in Table 5.1-1.

TABLE 5.2-1 DPS SHe TANK IMPLOSION SUMMARY

Failure Report	Date	S/N	Pressure	Comments
D6814	1-8-69	108	--	During removal from LM-6 it was noted that the outer shell had imploded; attributed to excessive handling.
FAE 8080	3-10-69	121	17.6 psia	During external proof test, unit imploded at 17.6 psia, attributed to marginal design resulting from weight reduction (screening test).
FAE 8079	9-16-69	120	17.95 psia	During external proof test, unit imploded at 17.95 psia; attributed to marginal design resulting from weight reduction (screening test).
DMT 508510	1-30-67	109	--	While assembling cover, unit imploded; failure attributed to excessive handling.
FAE 8071	3-28-67	112	18.8 psia	During external proof test, the unit imploded at 18.8 psia; the corrective action was to reduce the proof pressure from 19.5-20.0 psia to 18.25 ± .25 psia.
Non-reportable problem occurred prior to A. T.P. at vendor.	8-11-66	102	--	Unit imploded due to handling damage (pushed in); repaired with doubler.
	9-67	102	--	During loading movement of tank, a sling wrapped around a line and imploded the tank; repaired with new outer shell

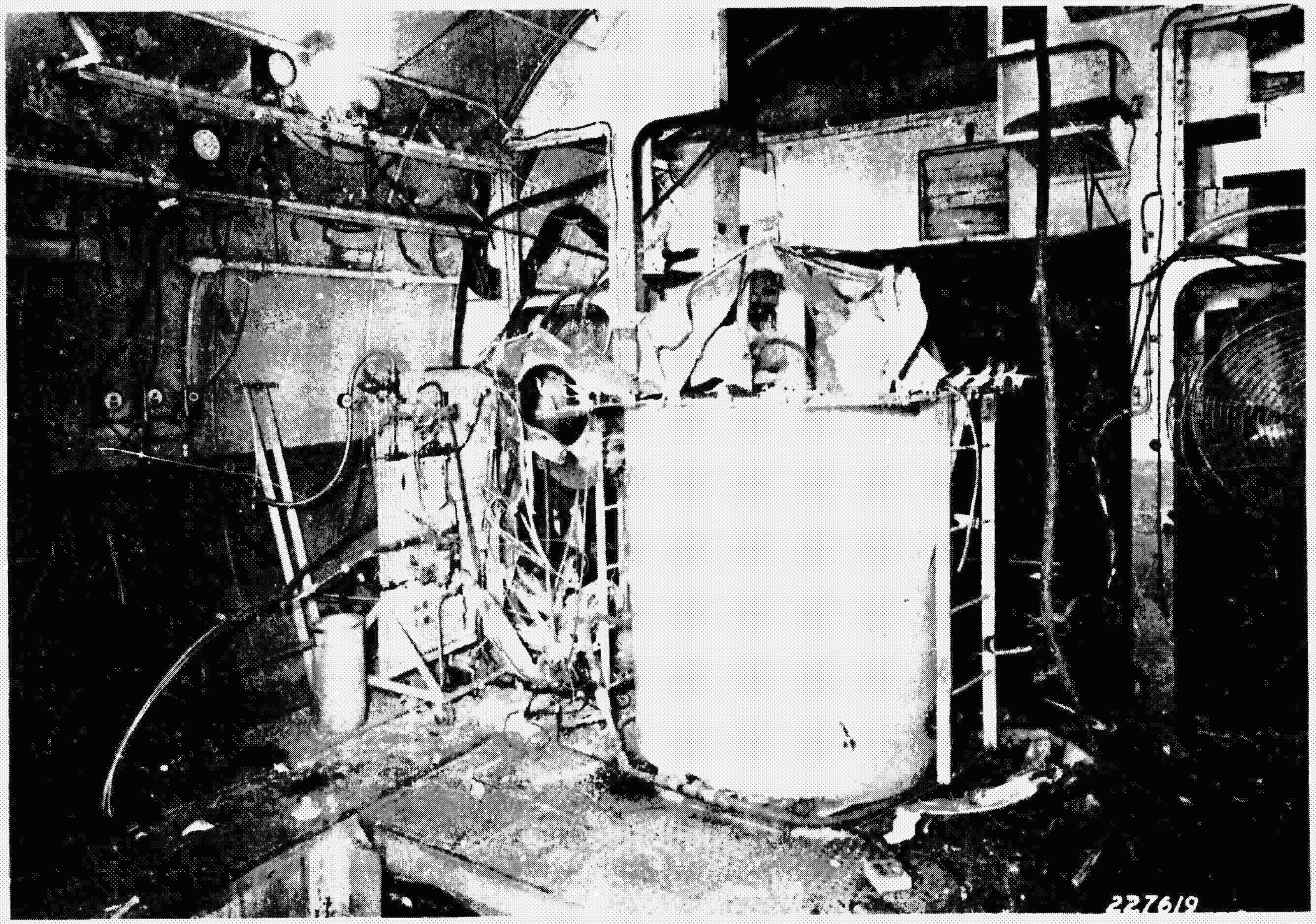


Fig. 5.2-1   Test Cell View After DPS Propellant Tank Failure

Fig. 5.2-2 Reassembled Pieces of DPS Propellant Tank Cover

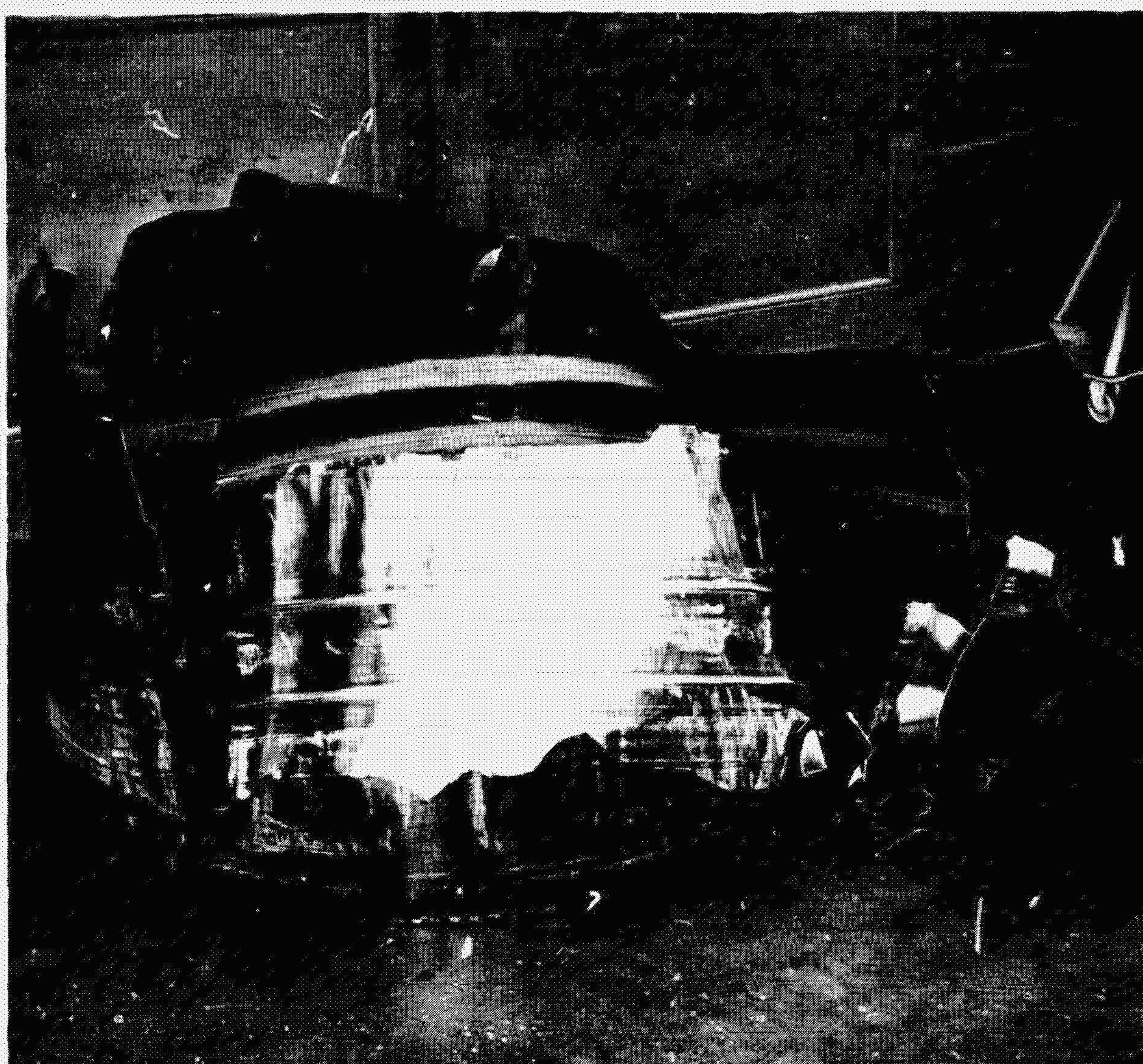


Fig. 5.2-3 DPS Propellant Tank Failed Cylindrical Section

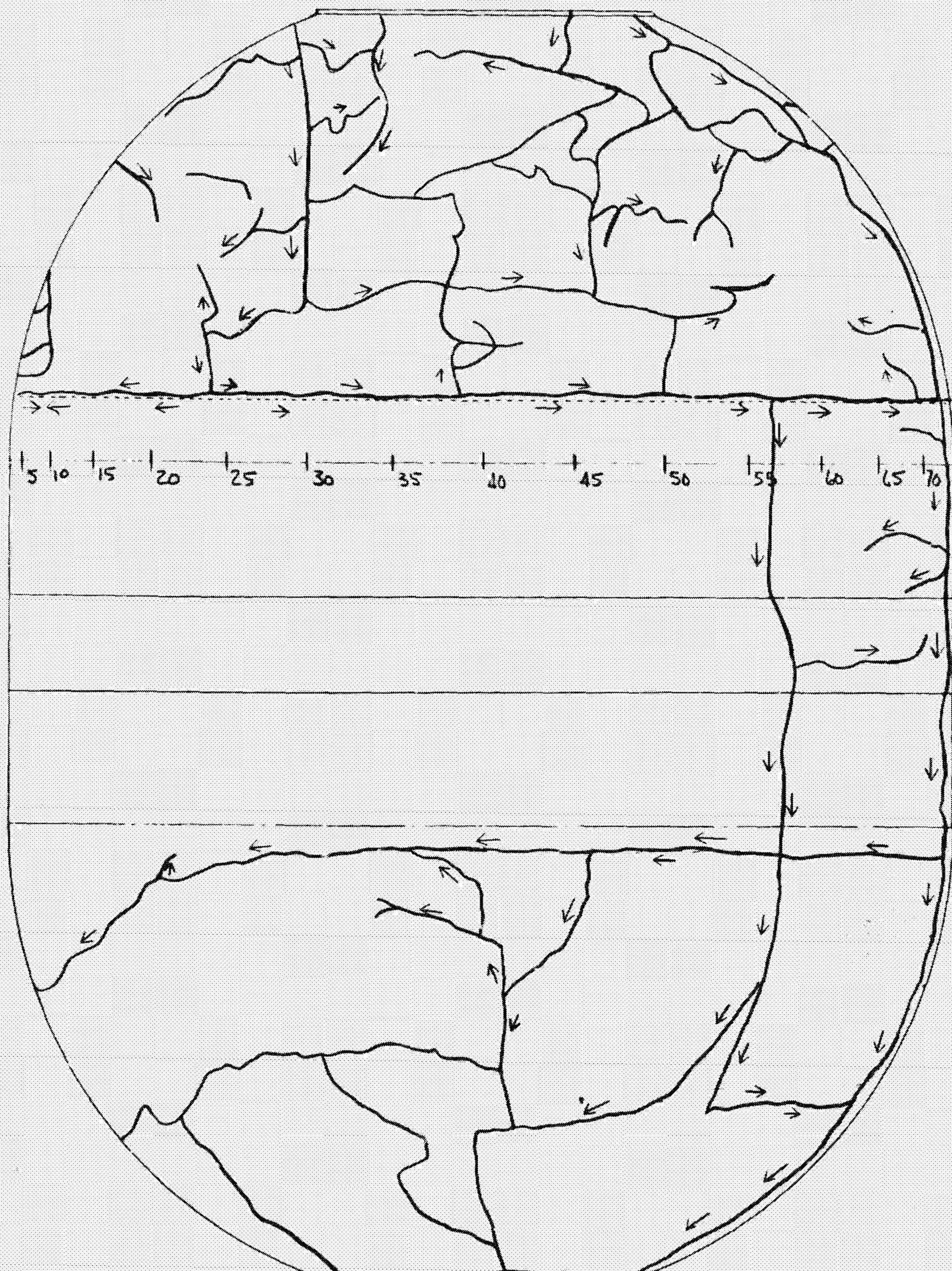


Fig. 5.2-4   Reconstruction of DPS Propellant Tank Failure

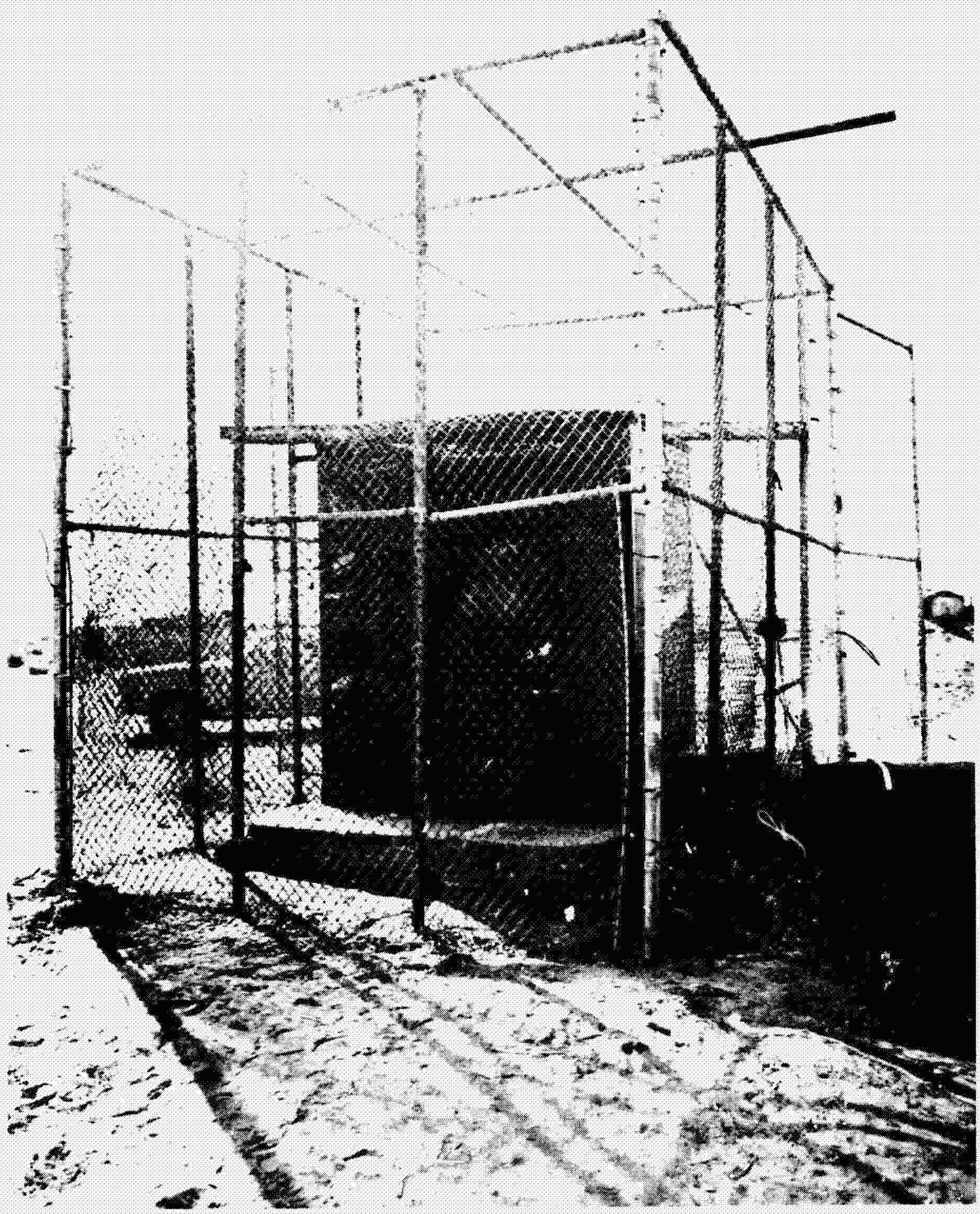


Fig. 5.2-5 Test Facility Before SHe Tank Pneumatic Rupture

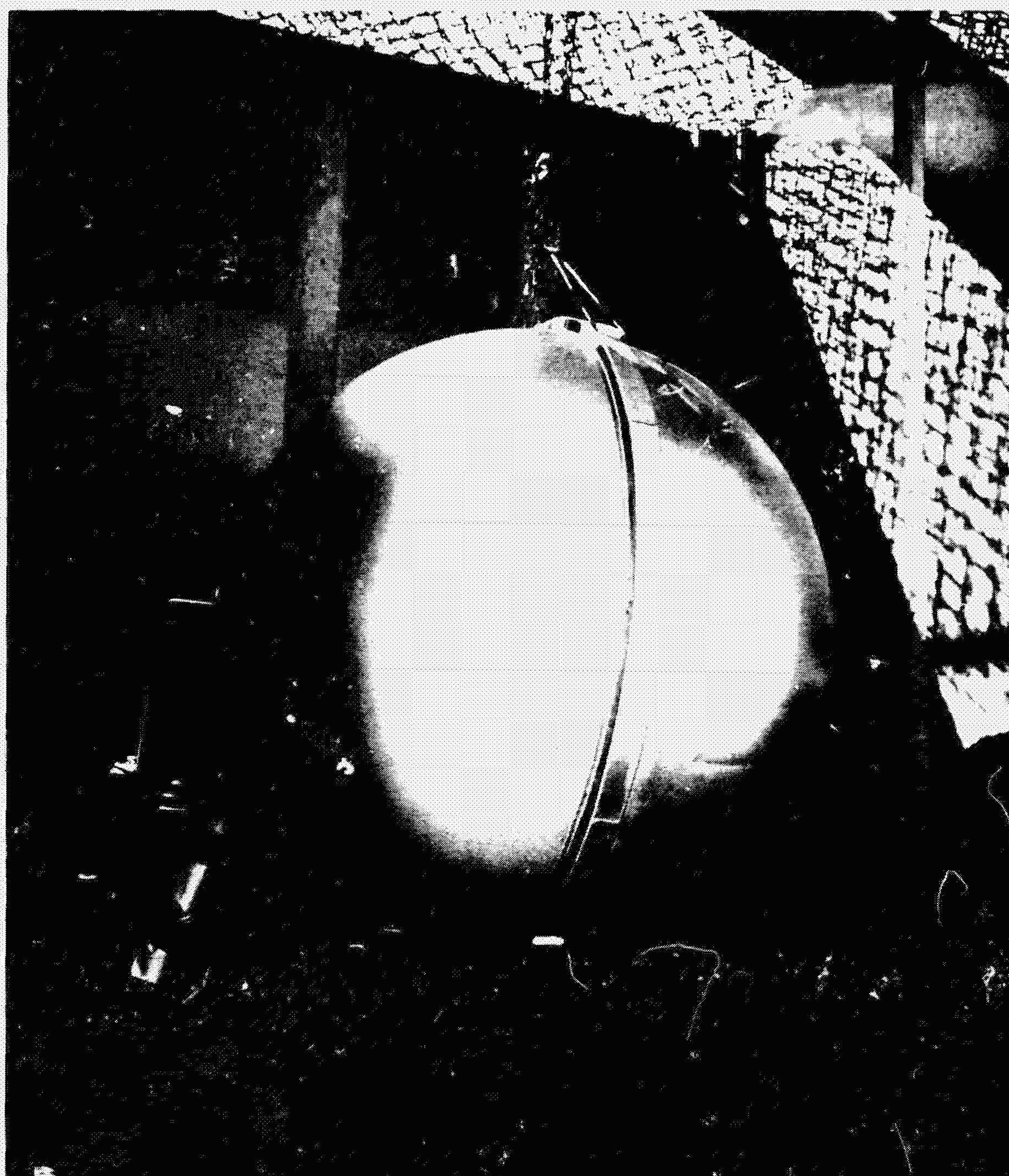


Fig. 5.2-6 SHe Tank Test Setup

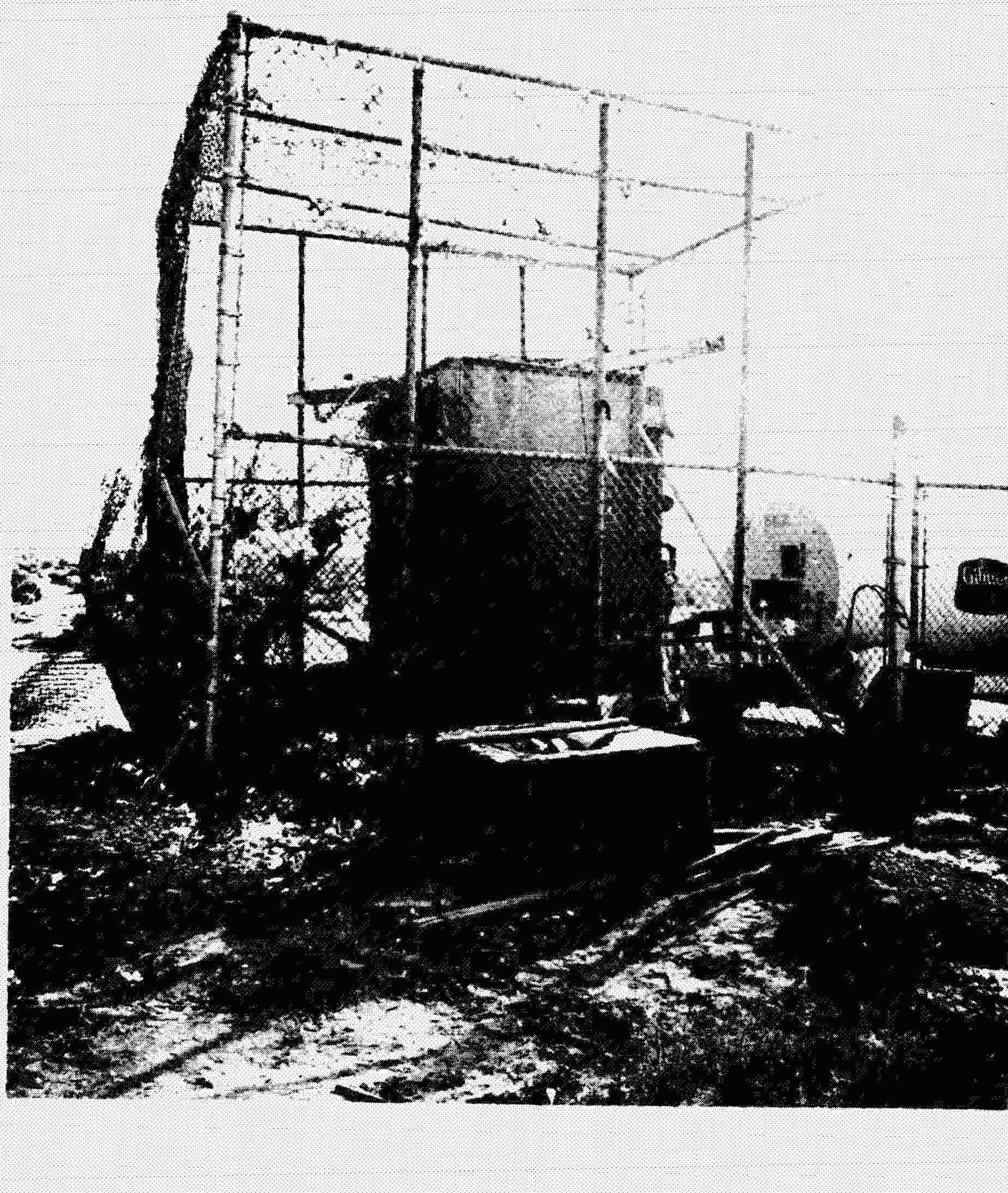


Fig. 5.2-7 Test Facility After SHe Tank Pneumatic Rupture

Fig. 5.2-8 SHe Tank Pieces After Pneumatic Rupture

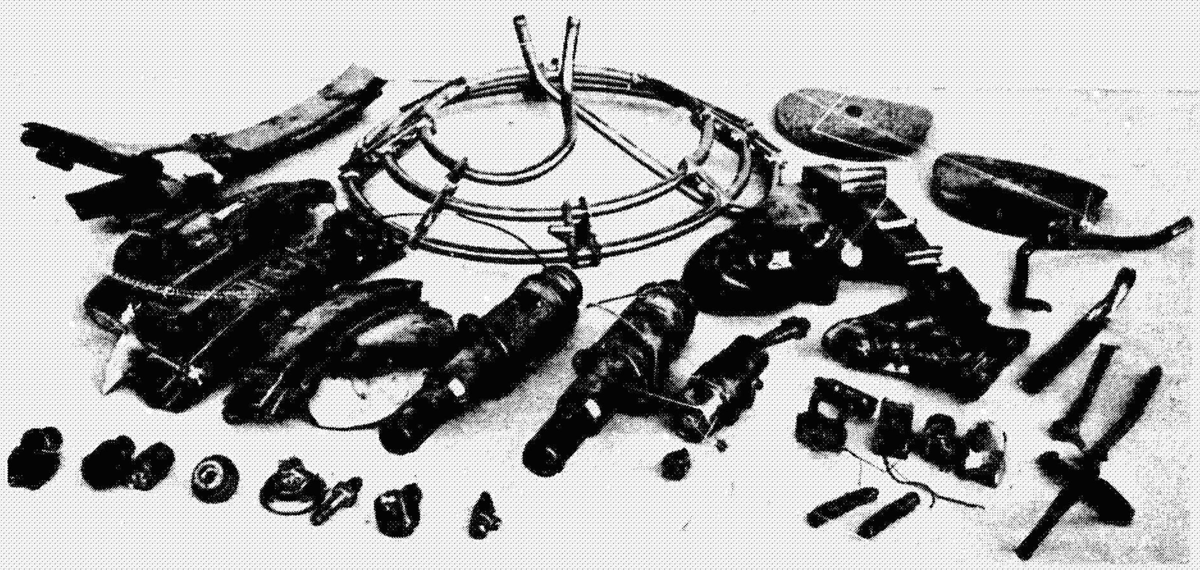


Fig. 5.2-9 SHe Tank Pieces After Pneumatic Rupture

5.3 ASCENT PROPULSION SUBSYSTEM

5.3.1 Ascent Propellant Tanks

Six ascent propellant tanks were hydrostatically tested to burst. Test results are summarized in Table 5.1-1. Figure 5.3-1 shows the results of a hydrostatic tank failure.

The propellant tank was subjected to a hydrostatic test which consisted of the tank assembly being pressurized in 25-psi increments to 250 psig. After a 2-minute hold at 250 psig, the pressure was held momentarily at each pressure increment to obtain the necessary strain gage data. After a 2-minute hold at 375 psig, the pressure was increased at a constant rate of 20 psi per minute until burst occurred at 452 psig.

The updated tank which burst at 478 and 494 psig, differed from the original design in that it is an all-welded configuration. This change was effective on LM-6 and subsequent.

A review of the failure history indicates one failure which would have resulted in significant loss of oxidizer from the tank. On 2 November 1965, during compatibility testing of the ascent oxidizer tank, a pressure loss of 2.5 psi/min was observed. The failure occurred after approximately 47 hours of testing at 245 $\pm$ 5 psi at a temperature of 103°F. Visual inspection revealed that a $\frac{1}{2}$ inch crack had developed in the membrane area of the parent material of the tank. The vendor indicated that it was highly probable that an inherent incompatibility existed between the titanium and N_2O_4 used during the testing. The problem has been resolved by adding an inhibitor (NO) and controlling the water content. An additional requirement is to avoid numerous pressure cycles of the stored N_2O_4. The pressure cycling tends to remove the inhibiting agent from the propellant.

Subsequent to verification of the cause of failure and improvement in the N_2O_4, the compatibility test was repeated utilizing two tanks for 75 days at 310 psi and a temperature of 100°F. No leakage was noted during the test. After the exposure period, the tanks were pressurized with water at ambient temperature; rupture occurred at 558/512 psig.

5.3.1 cont'd

No compatibility test was conducted o the ascent fuel tank. Sufficient data exist to demonstrate that titanium is compatible with Aerozone-50.

In addition to the above testing, a design verification test was completed on 5 September 1966. The test consisted of proof pressure, vibration, creep, pressure cycling, acceleration and burst. The tank was hydrostatically pressurized; rupture occurred at 465 psig at ambient temperature.

5.3.2 Ascent Helium Tank

Two APS helium tanks were subjected to the following test environments during pressure tests:

- Proof pressure to 4650 ± 10 psig at 160°F for 5 minutes
- Four hundred pressure cycles from 100 to 3500 psig at 1 cycle/min
- Creep test - 312 hours at 3500 psig 160°F
- Burst Testing - 5250 psig at 160°F minimum

The burst test data are summarized in Table 5.1-1. Figure 5.3-2 shows the results of a hydrostatic tank failure.

The pressure was increased hydrostatically in 30-second increments of 500 psi until a pressure of 4,700 psig was reached and then increased in two increments to 5,250. The pressure was then gradually increased until rupture occurred at 5,740/5,500 psig.

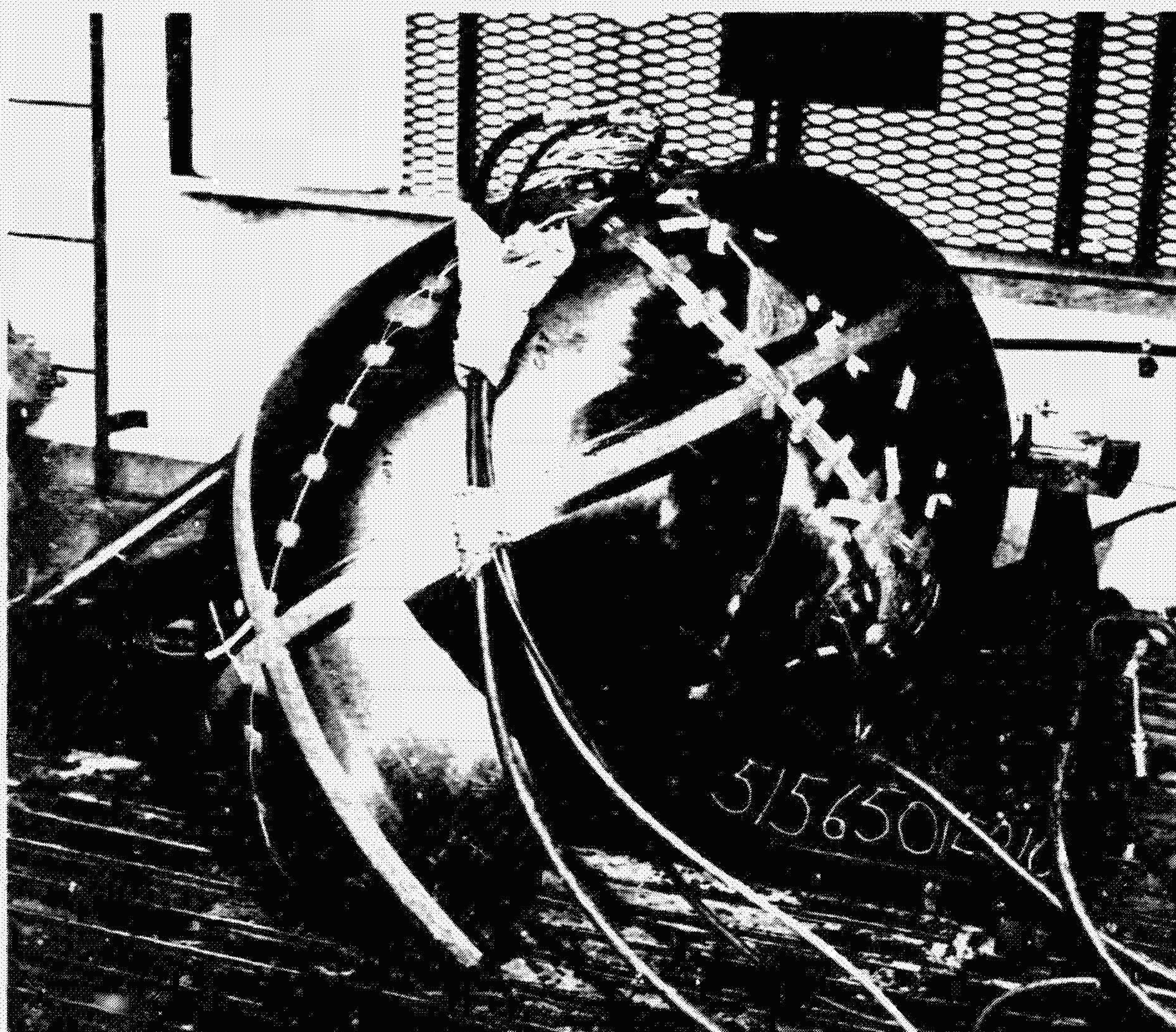


Fig. 5.3-1   APS Propellant Tank After Hydrostatic Rupture

Fig. 5.3-2 APS He Tank After Hydrostatic Rupture

5.4 REACTION CONTROL SUBSYSTEM

5.4.1 Propellant Tanks

Four RCS propellant tanks were hydrostatically tested to burst; test results are summarized in Table 5.1-1. Figure 5.4-1 shows typical results of the burst test. Tanks were flight configured except that the teflon bladder was removed. At MSC, on 9 April 1969, an incorrect procedure caused a vacuum to be pulled on LM-2 oxidizer tank LSC 310-405-11 and fuel tank LSC 310-405-12 which then collapsed under atmospheric pressure. This is not possible under flight conditions.

5.4.2 Helium Tanks

Two RCS helium tanks were hydrostatically tested to burst; test results are summarized in Table 5.1-1. Figure 5.4-2 shows typical results of the burst test. Hydrostatic pressure was applied in 500 psi increments to 4700 psi, then in 250 psi increments to 5250 psi, the design burst pressure. Pressure was held at 5250 psi for 2 minutes, then raised to the burst pressure of 5700/5800 psi.

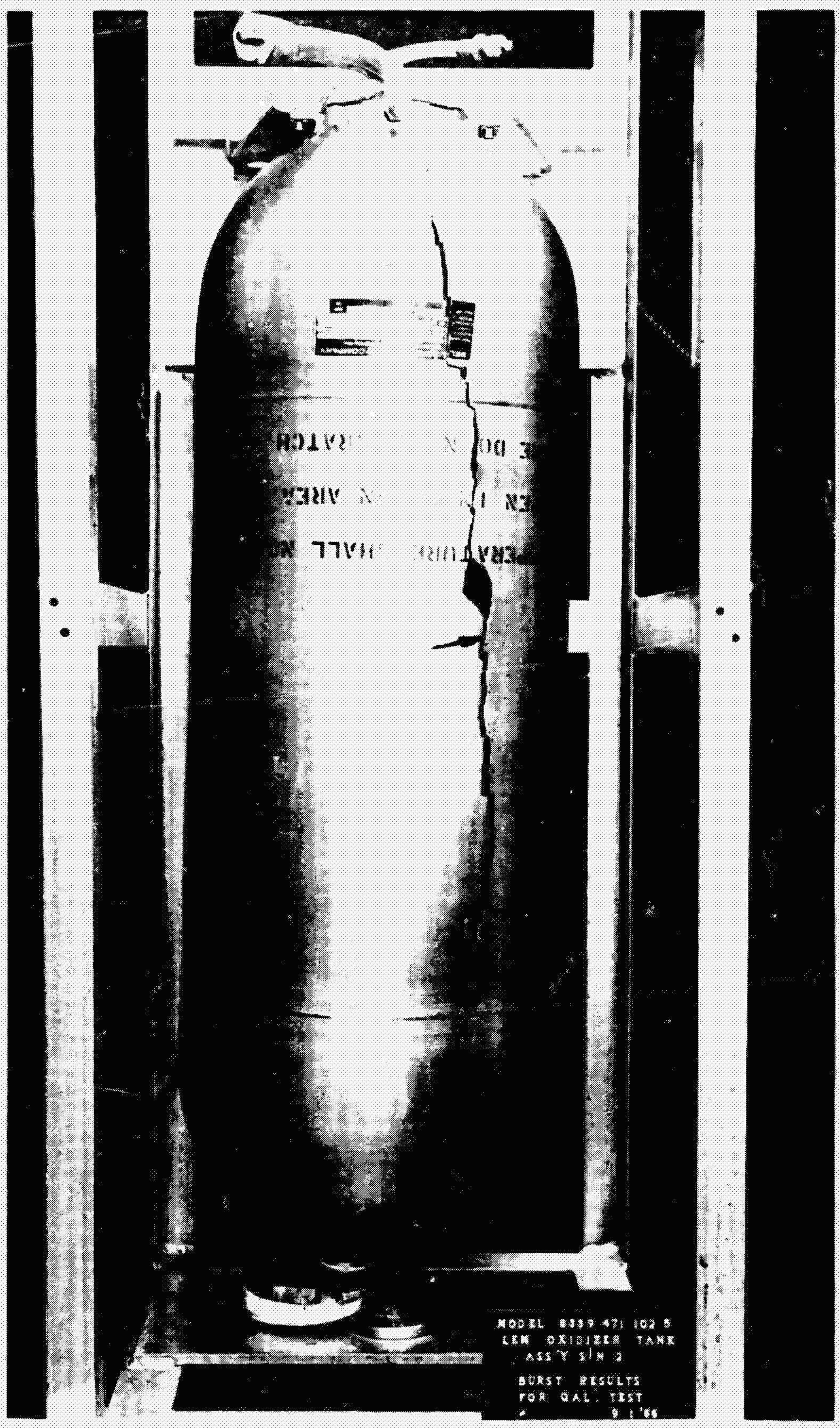


Fig. 5.4-1 RCS Propellant Tank After Hydrostatic Rupture

Fig. 5.4-2 RCS He Tank After Hydrostatic Rupture

5.5 ENVIRONMENTAL CONTROL SUBSYSTEM

5.5.1 Descent Oxygen Tank

Six descent oxygen tanks were hydrostatically tested to burst; test results are summarized in Table 5.1-1. Figure 5.5-1 shows the typical results of a hydrostatic failure.

During a production acceptance test, a descent oxygen tank failed at 3000 psig. The test procedure is to perform one pressurization to proof pressure and fire pressurization cycles to MDOP. The proof pressure was maintained for 2 min and each MDOP was maintained for 1 min. This tank failed after 40 seconds of the 5th MDOP pressurization (ref. Failure Report FA1001). Failure was attributed to a crack in the tank material which had not been detected. There was an added stress corrosion factor involved because of immersion of the tank in water during the tests. Subsequent action included tank redesign, elimination of the water immersion and increased QC coverage.

5.5.2 Ascent Oxygen Tank

Four ascent oxygen tanks were hydrostatically tested to burst; test results are summarized in Table 5.1-1. Typical results of tank burst tests are shown in Fig. 5.5-2.

5.5.3 Ascent Stage Water Tank

One ascent water tank was hydrostatically tested to burst; test results are summarized in Table 5.1-1. The failed tank is shown in Fig. 5.5-3.

5.5.4 Descent Stage Water Tank

One descent water tank was hydrostatically tested to burst; test results are summarized in Table 5.1-1. The failed tank is shown in Figure 5.5-4.

Fig. 5.5-1 ECS D/S GOX Tank After Hydrostatic Rupture

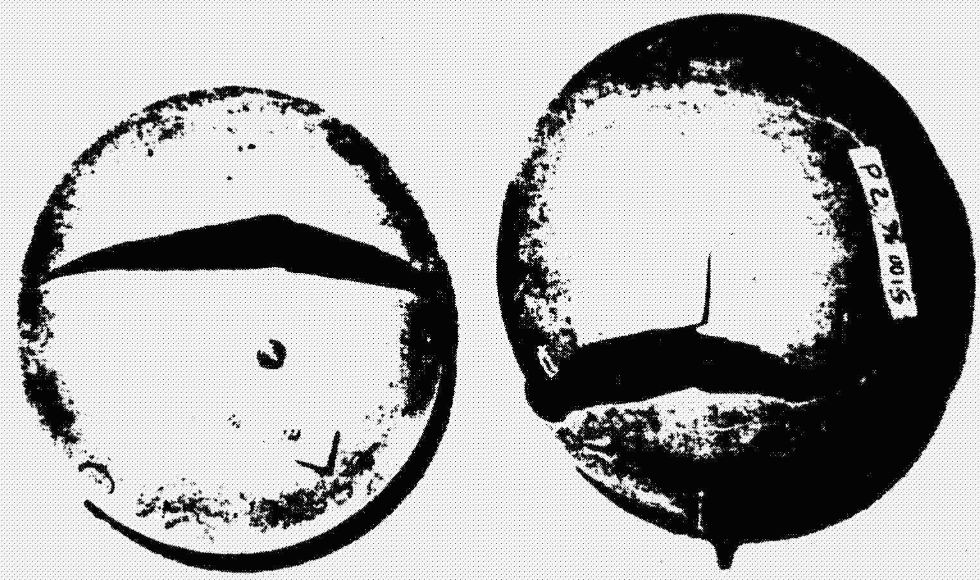


Fig. 5.5-2   ECS A/S GOX Tanks After Hydrostatic Rupture

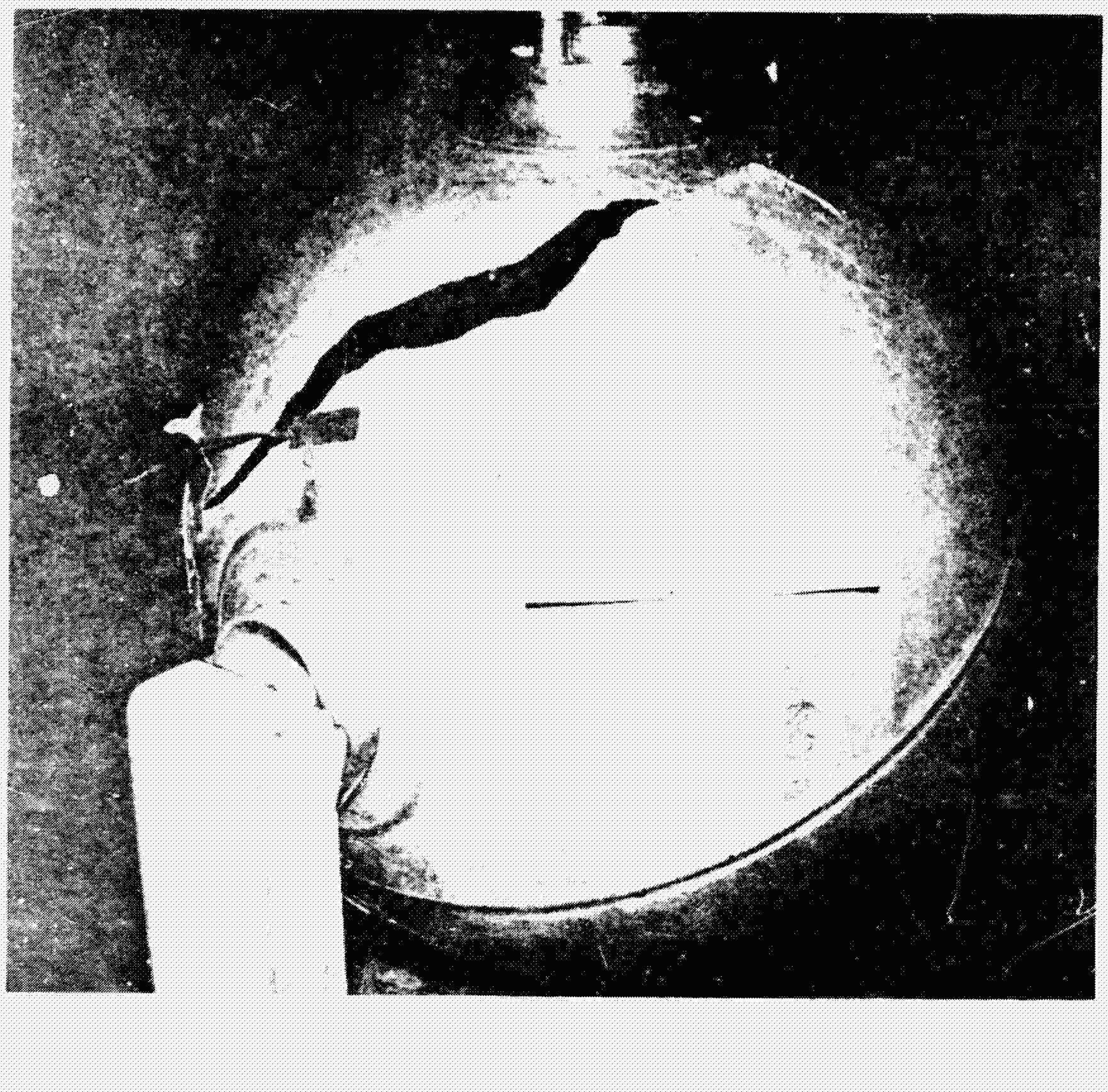


Fig. 5.5-3   ECS A/S Water Tank After Hydrostatic Rupture

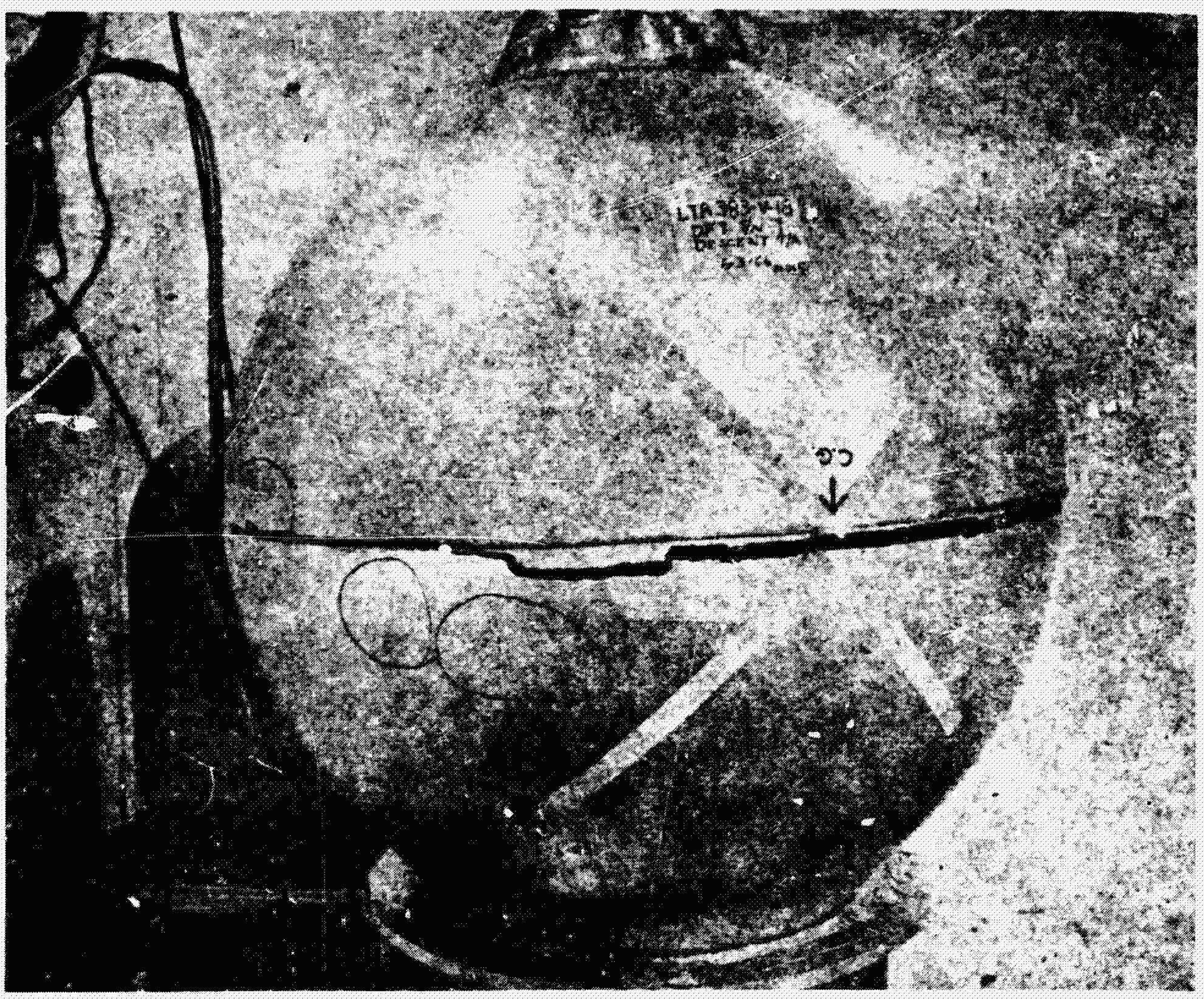


Fig. 5.5-4   ECS D/S Water Tank After Hydrostatic Rupture

5.6 BATTERIES

All LM battery containers have vent valves to provide relief while generating gas. The opening and closing pressures of the vent valves on the primary batteries are checked just before battery installation at KSC. The vent valves of the pyro batteries are checked as piece parts early in the manufacturing flow. However, the LM pyro batteries do have test ports in the container which could be used to check the vent valve operation at KSC in the same manner as the primary batteries.

The primary and ED battery containers have never been tested for over-pressurization. Analysis has shown that once the battery has been over-pressurized it will relieve (not rupture) through its weakest point. For the primary batteries, this is the interface of the battery container and cover at the rubber gasket.

The estimated pressure when permanent yielding would occur in the battery cover is 36.3 psig maximum. Leakage will occur at a pressure well below 35 psig, since the variables such as O-ring and cover irregularities along with case wall and bolt tolerances were not taken into account in the calculations and will act to lower the holding pressure of the container. This relief method will not be explosive and will not present a source of shrapnel damage, although KOH will be spilled.

There have been two isolated incidents where inadvertent ED battery case ruptures have occurred. These ruptures occurred during laboratory over-testing during which the vent relief valves were sealed. In both cases there was internal pressure buildup and subsequent case rupture at the rear corner seam of the battery. They were simple ruptures presenting no shrapnel effects.

There are two Apollo 13 anomalies associated with the descent batteries.

a. Telemetry data show that at 97 hours, 13 minutes and 56 seconds, battery 1 current surged to 30 amperes, battery 2 current exceeded 60 amperes, battery 3 surged to 37 amperes and battery 4 surged to 31 amperes. For a

short time following the glitch battery 2 carried approximately 80 percent of the load. Load sharing subsequently returned to the pre-glitch condition of 3 to 4 amperes per battery. A corresponding decrease in buss voltages was experienced. At 97 hours, 14 minutes and 42 seconds, the lunar module pilot reported hearing a thump and seeing snow flakes from the descent stage.

b. At approximately 100 hours, a battery malfunction light illuminated with a corresponding master alarm. The malfunction was isolated to the number 2 by onboard testing. The battery malfunction light extinguished when the battery was removed from the buss but illuminated immediately when the battery was reconnected more than an hour later. A malfunction light indicates either battery overtemperature, overcurrent, or reverse current.

Test and analyses are being conducted to determine the causes and relationships between these anomalies.

5.7 TRANSDUCERS

All LSC 360-605-303 immersion probe temperature transducers are proof tested (collapse) to 2000 psia. Approximately 130 transducers have been tested during the LM program with no leakage failures. The design collapse pressure specification of 4000 psia has not been tested for the -303 design. A similar unit (-301) of the same design, but 1.3 in. shorter, was tested to 8000 psig during qual and 6000 psig during DVT with no leakage.

All absolute pressure transducers are proof tested at ambient temperature. The proof-test and design burst pressure levels are shown in Table 5.7-1. Approximately 1000 units have been proof tested on the LM program with no leakage failures. However, no burst pressure tests have been performed for these transducers. A 350-psi 1025-series transducer, that is similar to the LSC 360-624 units, was tested to 13,000 psi without failure. In addition, transducers similar to the LSC 360-601 series have been burst tested by the vendor to levels in excess of 5 times the rated range.

Table 5.7-1

Absolute Pressure Transducer

Proof and Design Burst Pressure Summary

Transducer	Proof * Pressure	Design Burst Pressure *	
		Sensing Element	Reference Chamber
LSC 360-601-XXX-3 or LSC 360-601-XXX-2-1	2x if < 1000 psia 1.5x if > 1000 psia	5x	2x or 5000 psia, whichever is lower.
LSC 360-624-XXX-2	2x	5x	2x
LSC 360-624-1-31	2x	5x	650 psia

* NOTE: Proof and design burst pressure as a function of the rated pressure range.

6. DAMAGE POTENTIAL

6.1 SUMMARY

This section presents the results of the analysis performed to evaluate the potential damage to a LM from a ruptured pressure vessel. For this study, it has been assumed that a ruptured pressure vessel can fail in one or two ways: fragmentation or leakage; these failure modes are defined as follows:

- o Fragmentation - A pressure vessel rupture resulting in shrapnel, pressure forces and fluid loss
- o Leakage - A pressure vessel rupture resulting in pressure forces and fluid loss.

For this study it has been assumed that any LM tank that fragments with a TNT potential $>$ 0.1 lb will result in the loss of the vehicle and/or crew due to shrapnel and the close proximity of other pressure vessels, vital equipment, electrical cables and/or plumbing.

On the other hand, a leakage failure will result in no shrapnel, but will have the potential to damage the LM to a lesser extent from the hydrostatic/pneumatic forces and the fluid corrosive effects. The pneumatic forces from a ruptured high-pressure tank could damage such LM structure as descent stage beam panels and thermal shielding. Jagged edges of a ruptured tank, even through still attached to the tank, could sever electrical cabling, or introduce a structural flaw in an adjacent pressure vessel or fluid line. The effects of spillage of the tank contents are discussed in Section 4 for N_2O_4.

Tables 6.1-1 and 6.1-2 summarize the predicted failure modes for the LM pressure vessels as a function of the following mission phases; this assessment was based on the TNT equivalencies presented in Para. 6.2 and fracture mechanics considerations. The tank critical pressures listed in Tables 6.1-1 and 6.1-2 are based on fracture mechanics calculations and are used to determine the pressure below which the tank will leak as opposed to fragment upon failure as a result of tank material flaws. It must be recognized, however, that fragmentation failure of one tank may cause another tank to be penetrated with a sufficiently large piece of metal to cause fragmentation of the second tank. This can occur even at pressures below which the tank would normally leak as a result of material flaws.

6.1 cont'd

Mission Phase No.	Mission Phase Event
1	Launch
2	Earth Orbit
3	Translunar Coast
4	Lunar Orbit to Touchdown
5	Lunar Surface Activity
6	Lunar Ascent
7	Lunar Orbit

This section also presents a discussion in Para. 6.4 of the effects of loss or degradation of the LM thermal blankets.

TABLE 6.1-1

PREDICTED FAILURF MODE AT MAX. OPERATING PRESSURE PER MISSION PHASE

S/S	TANK/ CRIT. PRESS.	MISSION PHASE 1	2	3	4	5	6	7
RCS	HELIUM 1242 PSI.	F1	F1	F1	F1	F1	F1	F1
RCS	FUEL "A" 247.5 PSI.	F2	F2	F2	F2	F2	F2	F2
RCS	FUEL "B" 247.5 PSI.	F2	F2	F2	F2	F2	F2	F2
RCS	OXODIXER "A" 247.5 PSI.	F2	F2	F2	F2	F2	F2	F2
RCS	OXIDIZER "B" 247.5 PSI.	F2	F2	F2	F2	F2	F2	F2
DPS	SUPER CRIT. HE.	F1	F1	F1	F1	F1	N/A	N/A
DPS		Not considered by fracture mechanics analysis in this report, however, considered an F1 by virtue of TNT equivalency.						
DPS	AMB. HELIUM 805 PSI.	F1	F1	F1	F1	L	N/A	N/A
DPS	FUEL 118.7 PSI.	F2	F2	F2	F2	F1 Vented	N/A	N/A
DPS	OXIDIZER 118.7 PSI.	F2	F2	F2	F2	F1 Vented	N/A	N/A
APS	HELIUM 938 PSI.	F1	F1	F1	F1	F1	F1	F1
APS	FUEL 172 PSI.	F2	F2	F2	F2	F2	F1	F1
APS	OXIDIZER 172 PSI.	F2	F2	F2	F2	F2	F1	F1
ECS	A/S O_2(1) 1542 PSI.	L	L	L	L	L	L	L
ECS	A/S O_2(2) 1542 PSI.	L	L	L	L	L	L	L
ECS	D/S O_2 1621PSI.	F1	F1	F1	F1	F1	N/A	N/A
ECS	A/S H_2O 390 PSI.	L	L	L	L	L	L	L
ECS	D/S H_2O 243 PSI.	L	L	L	L	L	N/A	N/A

KEY: F1 - Fragmentation, TNT Equivalency >.1 lb F2 - Fragmentation, TNT Equivalency <.1 lb
L - Leakage Only

TABLE 6.1-2
PREDICTED FAILURE MODE AT BURST PRESSURE PER MISSION PHASE

S/S	TANK/ CRIT. PRESS	MISSION PHASE 1	2	3	4	5	6	7
RCS	HELIUM 1242 PSI.	F1	F1	F1	F1	F1	F1	F1
RCS	FUEL "A" 247.5 PSI.	F2	F2	F2	F2	F2	F2	F2
RCS	FUEL "B" 247.5 PSI.	F2	F2	F2	F2	F2	F2	F2
RCS	OXIDIZER "A" 247.5 PSI.	F2	F2	F2	F2	F2	F2	F2
RCS	OXIDIZER "B" 247.5 PSI.	F2	F2	F2	F2	F2	F2	F2
DPS	SUPER CRIT. HE.	F1	F1	F1	F1	F1	N/A	N/A
		Not considered by fracture mechanics analysis in this report, however, considered an "F1" by virtue of TNT equivalency.						
DPS	AMB. HELIUM 805 PSI.	F1	F1	F1	F1	L	N/A	N/A
DPS	FUEL 118.7 PSI.	F2	F2	F2	F2 / F1	Vented	N/A	N/A
DPS	OXIDIZER 118.7 PSI.	F2	F2	F2	F2 / F1	Vented	N/A	N/A
APS	HELIUM 938 PSI.	F1	F1	F1	F1	F1	F1	F1
APS	FUEL 172 PSI.	F2	F2	F2	F2	F1	F1	F1
APS	OXIDIZER 172 PSI.	F2	F2	F2	F2	F1	F1	F1
ECS	A/S O_2(1) 1542 PSI.	F2	F2	F2	F2	F2	F2	F2
ECS	A/S O_2(2) 1542 PSI.	F2	F2	F2	F2	F2	F2	F2
ECS	D/S O_2 1621 PSI.	F1	F1	F1	F1	F1	N/A	N/A
ECS	A/S H_2O 390 PSI.	L	L	L	L	L	L	L
ECS	D/S H_2O 243 PSI.	L	L	L	L	L	N/A	N/A

KEY: F1 - Fragmentation, TNT Equivalency $>$ .1 lb F2 Fragmentation, TNT Equivalency $<$ .1 lb
L - Leakage Only.

6.2 TNT EQUIVALENCY

TNT equivalency for all LM pressure vessels have been derived for the major mission phases. The TNT values, calculated for both tank maximum operating pressures and burst pressures (limit pressure), are presented in Tables 6.2-1 and 6.2-2, respectively.

A constant temperature was assumed in calculating the TNT values from the following equation:

$$\text{Pounds of TNT} = \frac{PV}{(\gamma - 1)\,1.4 \times 10^{-6}}$$

Where P = pressure (psf)

V = gas volume (cu. ft)

γ = ratio of specific heats (gas only)

$1.4 \times 10^{-6}\ \frac{\text{Work}}{\text{lb TNT}}$ = TNT equivalency conversion factor.

The following data are presented to provide a comparative measure for the LM pressure vessel TNT equivalencies:

Explosive Device	Lb TNT Equiv.
Rifle Primer (or Firecracker)	0.000092
.22 Long Rifle Cartridge	0.000232
.45 Pistol Cartridge	0.000563
No. 8 Electric Blasting Cap	0.00127
.30 M2 Ball Rifle Cartridge	0.00480
.50 M2 Ball MG Cartridge	0.0226
20 MM HE Projectile	0.025
MKII Fragmentation Hand Grenade	0.125
One Stick (one lb) 100% Gel. Dynamite	~1
Antitank Mine	5

TABLE 6.2-1 TNT EQUIVALENCIES

TANK \ MISSION PHASE	LAUNCH	LOI	LM ACTIVATION	LUNAR TOUCHDOWN	LUNAR LIFTOFF	ASCENT BURN OUT	LM/CSM DOCK	MAX TNT EQUIVALENCY*
	TNT EQUIVALENCY (LB)/MAX. OPERATING PRESSURE (PSIA) AS A FUNCTION OF MISSION PHASE							
RCS								
- Helium	0.267/3500	→	→	0.245/3210	0.245/3210	0.245/3210	0.231/3120	0.267/3500
- Fuel A	3.5×10^{-4}/250	→	→	0.0088/250	0.0096/250	0.0096/250	0.0328/250	0.071/250
- Fuel B	3.5×10^{-4}/250	→	→	0.0103/250	0.0106/250	0.0106/250	0.0320/250	0.071/250
- Oxid A	2×10^{-4}/250	→	→	0.0116/250	0.0125/250	0.0125/250	0.0376/250	0.089/250
- Oxid B	2×10^{-4}/250	→	→	0.0124/250	0.0133/250	0.0133/250	0.0428/250	0.089/250
DPS								
- SHe	0.340/405	0.77/915	0.87/1035	0.42/500	N/A	→	→	1.438/1710
- Amb. He	0.269/1750	→	→	0.135/876	N/A	→	→	0.269/1750
- Fuel	0.051/270	→	→	2.15/270	N/A	→	→	2.61/270
- Oxidizer	0.038/270	→	→	2.43/270	N/A	→	→	2.61/270
APS								
- Helium	1.78/ 0	→	→	→	→	0.646/1270	0.646/1270	1.78/3500
- Fuel	0.017/250	→	→	→	→	1.36/250	1.36/250	1.387/250
- Oxidizer	0.009/250	→	→	→	→	1.32/250	1.32/250	1.387/250
ECS								
- A/S O_2 (1)	0.129/1000	0.129/1000	0.118/915	0.118/915	0.107/829	0.107/829	0.065/504	0.129/1000
- A/S O_2 (2)	0.129/1000	→	→	→	→	→	→	0.129/1000
- D/S O_2	2.4/3000	2.35/2940	2.35/2940	2.13/2660	N/A	→	→	2.4/3000
- A/S H_2O	0.0028/48.2	→	→	→	→	0.0027/41.1	0.0025/27.0	0.0028/48.2
- D/S H_2O	0.022/48.2	→	→	0.021/34.5	N/A	→	→	0.022/48.2

*Based on a worst-case combination of maximum operating pressure and gas volume; these values exist at full-tank conditions for the H_2O, O_2 and He tanks, and empty-tank conditions for the propellant tanks.

TABLE 6.2-2 TNT EQUIVALENCIES

TANK	BURST PRESS. (PSIA) \ MISSION PHASE	TNT EQUIVALENCY (LB) @ DESIGN BURST PRESSURE AS A FUNCTION OF MISSION PHASE: LAUNCH	LOI	LM ACTIVATION	LUNAR TOUCHDOWN	LUNAR LIFTOFF	ASCENT BURNOUT	LM/CSM DOCK	MAX. TNT EQUIVALENCY*
RCS									
- Helium	5250	0.400	→	→	→	→	→	→	0.400
- Fuel A	375	0.0005	→	→	0.0133	0.0144	0.0144	0.0494	0.110
- Fuel B	375	0.0005	→	→	0.0155	0.0160	0.0160	0.0481	0.110
- Oxid. A	375	0.0004	→	→	0.0174	0.0187	0.0187	0.0566	0.134
- Oxid. B	375	0.0004	→	→	0.0187	0.0200	0.0200	0.0645	0.134
DPS									
- SHe	3420	2.88	→	→	→	N/A	→	→	2.88
- Amb. He	2625	0.404	→	→	→	N/A	→	→	0.404
- Fuel	405	0.076	→	→	3.22	N/A	→	→	3.92
- Oxidizer	405	0.057	→	→	3.65	N/A	→	→	3.92
APS									
- Helium	5250	2.68	→	→	→	→	→	→	2.68
- Fuel	375	0.027	→	→	→	→	1.96	1.96	2.08
- Oxidizer	375	0.013	→	→	→	→	1.96	1.96	2.08
ECS									
- A/S O_2 (1)	1500	0.194	→	→	→	→	→	→	0.194
- A/S O_2 (2)	1500	0.194	→	→	→	→	→	→	0.194
- D/S O_2	4500	3.60	→	→	→	N/A	→	→	3.60
- A/S H_2O	96.4	0.0056	→	→	→	→	0.0063	0.0089	0.026
- D/S H_2O	96.4	0.044	→	→	0.059	N/A	→	→	0.176

*Based on theoretical maximum gas volume and burst pressure

6.3 FAILURE MODE AND EFFECT ANALYSIS

An FMEA was performed to identify those potential failures which might, as a secondary mode, result in a catastrophic vehicle failure, providing the first assumed tank failure is survived. This assumption, that the crew is not injured, is based on the cryogenic SM oxygen tank failure experienced on Apollo 13. The results of this FMEA are summarized in Table 6.3-1; this table identifies only secondary items immediately surrounding the failed tank that would further affect crew safety. The criticality for the first failure (Column 1) is based on the loss of fluid only. The phases of the mission, where the combination of a tank failure and the associated loss of an adjacent item is of concern, are indicated. The mission phases are defined in Para. 6.1.

The following paragraphs present discussions of the LM pressure vessels based on the results of this FMEA.

6.3.1 DPS Propellant Tanks

Loss of all the consumables in any or all of these tanks will impair the safety of the crew in the non-abort stage zone only. An explosive rupture of any of the propellant tanks may directly result in loss of the crew due to shrapnel, or cause a chain reaction explosion of the other tanks on the LM which would result in the loss of the crew. The following discussion indicates the concern for loss of items surrounding these tanks. The +Y or +Z propellant tank could affect the umbilical and/or E.D. wiring to the extent that staging would be impossible. Loss of either APS propellant tank would result in loss of the crew, assuming the failure occurred during powered descent. During any mission phase, there is a danger of hypergolic mixing if a propellant tank ruptures the complementary propellant manifold.

6.3.2 DPS Ambient He Tank, Descent GOX Tank and Supercritical Helium Tank

Loss of any or all of the consumables in these tanks would not impair the safety of the crew. Explosive rupture of any Quad III tank may result in loss of crew by shrapnel from any or all of the subject tanks or loss of any of the following in the non-abort stage zone: DPS oxidizer tank No. 1, DPS fuel tank No. 1, DECA, and DPS engine. In addition, the descent fuel and oxidizer lines on the lower deck of Quad III or the RCS propellant lines above Quad III,

could be ruptured, resulting in hypergolic mixing, and/or the staging capability could be lost if the ED lines from both ED systems to an interstage fitting are severed.

6.3.3 APS Propellant Tanks

Loss of the consumable in either of these tanks is a crew safety consideration from lunar landing commitment to safe pericynthion orbit. Explosive rupture of either APS propellant tank can cause loss of crew due to shrapnel or cabin puncture. An explosive rupture of an APS propellant tank prior to lunar landing commitment, may, in turn, cause explosive rupture of the DPS propellant tank directly beneath it, or RCS tanks, and/or RCS fluid lines. This could result in loss of the crew due to shrapnel or hypergolic mixing. After safe pericynthion orbit there is still a concern for an APS tank explosive rupture due to shrapnel and possible propagation of RCS tank (s) explosive rupture.

6.3.4 RCS System and A/S Water Tanks

Loss of either one of the RCS or A/S H_2O tank consumables will not cause loss of crew. An explosive rupture of any RCS tank or A/S water tank may cause loss of crew due to secondary explosions of other nearby tanks (RCS and APS), shrapnel, or by cabin puncture when the crew is not in the closed suit loop mode. In addition, explosive rupture of any RCS tank can cause the loss of the redundant RCS system, thereby losing all vehicle attitude control, or cause leaks in lines and/or tanks containing the complementary propellant and result in hypergolic mixing.

6.3.5 Descent Water Tank

Loss of the descent water tank consumable would not impair the safety of the crew. Loss of crew may result if shrapnel from this tank punctures the cabin and the crew is not in the closed suit loop mode, or damages the adjacent D/S propellant tanks or fluid lines in the non-abort stage zone.

6.3.6 A/S GOX and He Tanks

Loss of all A/S GOX tanks consumables will not cause loss of crew since in the worst case, D/S GOX is used for cabin pressurization and the OPS's are available as an additional supply. Loss of consumables in any one of the He tanks will not cause loss of crew; however, after pressurization, a leak

in any He tank will cause loss of crew due to loss of all ascent He and loss of APS capability. An explosive rupture of any A/S GOX or He tank may result in loss of crew from shrapnel effects from any or all of these tanks, cabin rupture when the crew is not in the closed suit loop mode, or damage to the wiring assemblies or fluid lines in the Aft Equipment Bay (i.e., loss of all electrical power, ATCA loss resulting in the necessity of a hardover direct ascent from the lunar surface, loss of all active coolant, or loss of RCS control lines). In addition, the loss of nearby RCS fuel and oxidizer lines could result in hypergolic mixing or lead to loss of all RCS capability by depleting RCS consumables. Finally, the staging capability of LM could be lost if the ED electrical lines from both ED systems to an interstage fitting are severed.

6.3.7 <u>D/S GOX and Water Tanks (LM-10 and subsequent)</u>

Loss of any or all of the consumables in these tanks would not impair safety of the crew. Explosive rupture of either Quad IV tank may result in loss of crew by shrapnel or cabin puncture. Explosive rupture of these tanks may propagate explosion of the DPS fuel and oxidizer tanks, resulting in hypergolic mixing, or rupturing of a descent propellant tank in the non-abort stage zone, resulting in descent engine shutdown. Finally, the staging capability could be lost if the ED electrical lines from both ED systems to an interstage fitting are severed.

Table 6.3-1 - Summary Table For Fragmentation Type Failure Effects on the LM Vehicle

Tank and Functional Concern	Surrounding Safety Hazard Equipment	Major Additional Concern	Crit. Mission Phase 1	2	3	4	5	6	7	Remarks
Descent Oxidizer Tank (+Z) Functionally, explosive rupture of this tank causes shut-off of the descent engine. This failure causes loss of crew in the "non-abort stage zone" only.	Descent Water Tank (Quad #4) or GOX Tank (Quad #4) (LM-10 only).	Explosive Rupture	X	X	X	X	X			May result in chain reaction of high pressure tank explosions and/or cabin rupture due to shrapnel. Close proximity to desc. GOX tank which has high TNT potential.
	ED Relay Box & Wiring (Quad #4) or Umbilical Cutter (Quad #4).	Inadvertent cable cutting				X	X			See LED-550-175B for description of inadvertent cable cutting. Requires transfer of three relays in box or one squib actuation in cable assembly.
	Descent Engine fuel line	Hypergolic mixing	X	X	X	X	X			Close proximity of fuel line. Rupture may cause fire or explosion.
	Cabin	Puncture			X	X	X			Gross leak of cabin would cause loss of the crew, if they are not in a close suit loop mode.
	E.D. Nut & Bolt (Quad #1 or #4) or Umbilical Cutter	Staging				X	X	X		Close proximity of cables from redundant ED systems. Inability to stage vehicle.

Table 6.3-1 - Summary Table For Fragmentation Type Failure Effects on the LM Vehicle (Cont'd)

Tank and Functional Concern	Surrounding Safety Hazard Equipment	Major Additional Concern	Crit. Mission Phase							Remarks
			1	2	3	4	5	6	7	
D/S Oxid. Tank (-Z)	SHe Tank or GHe Tank or GOX Tank or Ascent Helium Tank (2).	Explosive Rupture	X	X	X	X	X			May cause chain reaction of high pressure tank bursts and/or cabin rupture.
Explosive rupture of this tank causes shutdown of descent engine. This failure causes loss of crew in non-abort stage zone only.	Descent Water Tank (Quad #2).	Explosive Rupture	X	X	X	X	X			Close proximity to descent fuel tank which has high TNT equivalent.
	RCS Engine lines (Sys.A&B) (Oxid. and Fuel).	Hypergolic mixing	X	X	X	X	X			Close proximity of oxid. and fuel lines. Rupture of both may cause explosion or fire.
		Loss of attitude control.				X	X			Close proximity of redundant systems. Damage upstream of isolation valves. Loss of all RCS fuel or oxid. Loss of attitude control capability.
	Aft Equip. Bay-Equip/Wiring/Glycol Plumbing	Loss of function(s)				X	X			Close proximity of all hardware. Loss of ATCA would cause loss of DAP & AAP enable. Only direct mode available for lunar ascent. Loss of veh.power and/or cooling.
	Fuel Manifold (Bottom -Z Comp)	Hypergolic mixing	X	X	X	X	X			Close proximity to oxid. tank. Rupture may cause an explosion or fire.
	Helium press. Module (2) APS	Gross external leak.				X	X			Loss of all APS helium. Inability to sustain ascent engine firing.

Table 6.3-1 - Summary Table For Fragmentation Type Failure Effects on the LM Vehicle (Cont'd)

Tank and Functional Concern	Surrounding Safety Hazard Equipment	Major Additional Concern	Crit. Mission Phase 1	2	3	4	5	6	7	Remarks
D/S Oxid. Tank (-Z) (Cont'd)	Ascent Glycol lines (Pri & Sec.)	Gross external leak.				X	X			Close proximity of Pri & Sec. loop. Loss of cooling of crew/critical equipment.
	ED Nut & Bolt Comb.	Staging				X	X			Close proximity of cables from redundant ED systems. Inability to stage vehicle.

Table 6.3-1 - Summary Table For Fragmentation Type Failure Effects on the LM Vehicle (Cont'd)

Tank and Functional Concern	Surrounding Safety Hazard Equipment	Major Additional Concern	Crit. Mission Phase 1	2	3	4	5	6	7	Remarks
Descent Fuel Tank (+Y)	Descent Water Tank (LM-10 only) (Quad #4)	Explosive Rupture	X	X	X	X	X			Close proximity to Descent GOX tank which has high TNT equivalent.
	GOX Tank (LM-10 only) (Quad #4)	Explosive Rupture	X	X	X	X	X			May cause chain reaction of high pressure tank bursts and/or cabin puncture.
	ED Relay Box and Wiring (Quad #4) or Umbilical Cutter (Quad #4)	Inadvertent Cable cutting				X	X			See LED-550-175B for effect of inadvertent cable cutting. Requires transfer of three relays in the box orone squib actuation in the cutter assembly.
	Oxid. Manifold (Bottom +Y Comp)	Hypergolic mixing	X	X	X	X	X			Close proximity of oxid.line. Rupture may cause fire or explosion.
	GHe Tank or GOX Tank or SHe Tank (Quad #3)	Explosive Rupture	X	X	X	X	X			May cause chain reactic of high pressure tank bursts and/or cabin puncture.
	ED Nut & Bolt Comb. (Quad #3) or Umbilical Cutter (Quad #4)	Staging				X	X			Close proximity of cables from redundant ED systems. Inability to stage vehicle.

Table 6.3-1 - Summary Table For Fragmentation Type Failure Effects on the LM Vehicle (Cont'd)

Tank and Functional Concern	Surrounding Safety Hazard Equipment	Major Additional Concern	Crit. Mission Phase 1	2	3	4	5	6	7	Remarks
Descent Fuel Tank (-Y)	Water Tank (Quad #2)	Explosive Rupture	X	X	X	X	X			Close proximity to descent oxid. tank which has high TNT equivalent.
	APS Fuel Tank (-Y Axis)	Primary explosive rupture.	X	X	X	X	X			May cause chain reaction of high pressure tank bursts and/or cabin puncture.
	ED Nut and Bolt Comb. (Quad #2).	Staging				X	X			Close proximity of cables from redundant ED systems. Inability to stage vehicle.

Table 6.3-1 - Summary Table For Fragmentation Type Failure Effects on the LM Vehicle (Cont'd)

Tank and Functional Concern	Surrounding Safety Hazard Equipment	Major Additional Concern	Crit. Mission Phase 1	2	3	4	5	6	7	Remarks
The following equipment are located in close proximity and are therefore, treated as a group: RCS Fuel Tank B RCS Oxid Tank B RCS Helium Tank B Ascent H_2O Tank #2 Functionally, the loss of any one or all of the fluids in these tanks will not result in loss of the crew at anytime in the mission.	Any one or all tanks in this area.	1) Explosive Rupture	X	X	X	X	X	X	X	May result in chain reaction of high pressure tank explosions and/or cabin rupture due to shrapnel.
		2) Hypergolic mixing	X	X	X	X	X	X	X	Close proximity to fuel tank. Rupture may cause explosion or fire.
	APS Oxidizer	1) Explosive Rupture	X	X	X	X	X	X	X	Same as 1 above.
		2) Hypergolic mixing	X	X	X	X	X	X	X	Same as 2 above.
	RCS Fuel and Oxid. lines for Quad 3 or 4.	1) Loss of RCS capability				X	X	X	X	Close proximity of redundant system. Damage upstream of isolation valves can result in loss of all RCS fuel or oxid. Loss of attitude control.
		2) Hypergolic mixing	X	X	X	X	X	X	X	Same as RCS Oxid. Tank B, Part 2.
	E.D. Nut/Bolt Combination #3.	Inability to stage.				X	X			Severing of the firing lines from both E.D. Systems will preclude staging.
	Wiring: EPS, COMM, INSTR.	Loss of all vehicle power.				X	X	X	X	Loss of vehicle control,ECS, Guidance, COMM., etc.
	Cabin	Rapid decompression of cabin.			X	X	X	X	X	Loss of crewif they are not in the closed suit loop mode.

Table 6.3-1 - Summary Table For Fragmentation Type Failure Effects on the LM Vehicle (Cont'd)

Tank and Functional Concern	Surrounding Safety Hazard Equipment	Major Additional Concern	Crit. Mission Phase 1	2	3	4	5	6	7	Remarks
The following equip. are located in close proximity and are therefore treated as a group. RCS Fuel Tank Sys. A RCS Oxid Tank Sys. A RCS He Tank Sys. A ASC H_2O Tank #1	Any one or all tanks in this area.	1) Explosive Rupture	X	X	X	X	X	X	X	May result in chain reaction of high pressure tank explosions and/or cabin rupture due to shrapnel.
		2) Hypergolic mixing	X	X	X	X	X	X	X	Close proximity to fuel tank. Rupture may result in explosion or fire.
	RCS Fuel and Oxid. lines for Quad 1 or Quad 2	1) Loss of RCS capability				X	X	X	X	Close proximity of redundant systems. Damage upstream of isolation valves can result in loss of all fuel or oxid. Loss of attitude control.
		2) Hypergolic mixing	X	X	X	X	X	X	X	Close proximity of fuel and Oxid. line. Rupture of both may result in an explosion or fire.
	RCS Control Wiring (Oxid Tank only)	Loss of attitude control				X	X	X	X	Close proximity of RCS wiring. Loss of RCS engines. Loss of attitude control.
	ED Nut-Bolt Combination #2	Inability to stage				X	X			Will not be able to stage the vehicle if the nut/bolt combination firing lines are severed.
	Wiring; EPS, INST. COMM.	Loss of vehicle power.				X	X	X	X	Loss of environmental control and vehicle control.
	Cabin	Rapid decompression of cabin.			X	X	X	X	X	Loss of crew if they are not in the closed suit loop mode.

Table 6.3-1 - Summary Table For Fragmentation Type Failure Effects on the LM Vehicle (Cont'd)

Tank and Functional Concern	Surrounding Safety Hazard Equipment	Major Additional Concern	Crit. Mission Phase 1	2	3	4	5	6	7	Remarks
The following equip. are located in close proximity in the same area and are therefore treated as a group. Ascent He 1 or 2 Ascent GOX 1 or 2 Functionally, a single Asc. Helium Tank rupture, after pressurization, would result in loss of all helium thus, precluding a lunar lift-off. Prior to pressurization, loss of one tank will not result in loss of crew since it can be isolated. Functionally, loss of a single Asc. GOX Tank will not cause loss of crew at any time in the mission.	Any one or all tanks in this bay.	1) Explosive Rupture	X	X	X	X	X	X	X	Rupture of tank may directly injure crew by shrapnel and/or propagate explosion of other high pressure vessels.
	D/S Oxidizer Tank (-Z)	Explosive Rupture	X	X	X	X	X			Same as above
	Cabin	Rapid decompression of cabin.			X	X	X	X	X	Loss of crew if they are not in the closed suit loop mode.
	Fuel and Oxid. lines feeding RCS engine Quad 2 or 3.	Loss of RCS capability.				X	X	X	X	Close proximity of redundant systems. Damage upstream of isolation valves would result in propellant depletion from both RCS systems.
		Hypergolic mixing	X	X	X	X	X	X	X	Close proximity of oxid. and fuel lines. Rupture of both may result in explosion or fire.
	Ascent He press. Modules (2)	Gross external leak.					X	X		Loss of APS He flow. Inability to maintain AE firing.
	AFT Equip. Bay-Equip/Wiring/ Glycol Plumbing	Electrical Shorting and/ or opens.				X	X	X	X	Close proximity of all hardware. Loss of any or all of the following: Attitude Control, VEH. power, Propulsion. Loss of ATCA would cause loss of DAP and AAP enable. Only direct mode available for lunar ascent.

Table 6.3-1 - Summary Table For Fragmentation Type Failure Effects on the LM Vehicle (Cont'd)

Tank and Functional Concern	Surrounding Safety Hazard Equipment	Major Additional Concern	Crit. Mission Phase 1	2	3	4	5	6	7	Remarks
ASC. He 1 or 2 ASC. GOX 1 or 2 (Cont'd)	ED Nut-Bolt Combination 1 or 2.	Nut and Bolt firing lines severed.				X	X			Close proximity of cables from redundant ED systems. Inability to stage vehicle.

Table 6.3-1 - Summary Table For Fragmentation Type Failure Effects on the LM Vehicle (Cont'd)

Tank and Functional Concern	Surrounding Safety Hazard Equipment	Major Additional Concern	Crit. Mission Phase 1	2	3	4	5	6	7	Remarks
Ascent Propulsion Oxidizer Tank (+Y)	RCS Oxidizer Tank (Sys. B) or RCS Helium Tank (Sys. B).	Explosive Rupture	X	X	X	X	X	X	X	May cause chain reaction of high pressure tank bursts and/or cabin rupture.
	RCS Fuel Tank (Sys. B) or Descent Propulsion Fuel Tank (+Y).	Explosive Rupture	X	X	X	X	X	X	X	May cause chain reaction of high pressure tank bursts and/or cabin rupture.
		Hypergolic mixing	X	X	X	X	X	X	X	Close proximity to oxid. tank. Rupture may result in explosion or fire.
Functionally, the loss of the ascent oxidizer tank would preclude a lunar ascent. This failure would result in loss of the crew if it occurs from the non-abort zone in powered descent through the lunar ascent minimum rescue orbit	RCS Engines (System A&B) Quad #3 or Quad #4.	Loss of both RCS systems.				X	X	X	X	Close proximity of redundant systems. Damage upstream of isolation valves. Loss of all RCS fuel & oxid. Loss of attitude control capability.
		Hypergolic mixing	X	X	X	X	X	X	X	Close proximity of oxid. & fuel lines. Rupture of both may result in explosion or fire.
	Umbilical Cutter and Wiring (Quad #4).	Inadvertent cable cutting.				X	X			See LED-550-175B for effect of inadvertent cable cutting.
	RCS Engine Control Wiring (Quads #3 & 4).	Loss of attitude Control				X	X	X	X	Close proximity of RCS cables. Loss of RCS engines. Loss of attitude control.

Table 6.3-1 - Summary Table For Fragmentation Type Failure Effects on the LM Vehicle (Cont'd)

Tank and Functional Concern	Surrounding Safety Hazard Equipment	Major Additional Concern	Crit. Mission Phase 1	2	3	4	5	6	7	Remarks
Ascent Propulsion Oxidizer Tank (+Y) (Cont'd)	Cabin	Rapid Decompression				X	X	X	X	Loss of crew if they are not in closed suit loop mode.
	ED Nut and Bolt Comb. or Umbilical Cutter.	Staging				X	X	X		Close proximity of cables from redundant ED systems. Inability to stage vehicle.

Table 6.3-1 - Summary Table For Fragmentation Type Failure Effects on the LM Vehicle (Cont'd)

Tank and Functional Concern	Surrounding Safety Hazard Equipment	Major Additional Concern	Crit. Mission Phase 1	2	3	4	5	6	7	Remarks
Ascent Fuel Tank	RCS Fuel, He and/ or Oxid. Tank Sys. A or Des. Fuel Tank	1) Explosive Rupture	X	X	X	X	X	X	X	May result in chain reaction of high pressure tank explosions and/or cabin rupture due to shrapnel.
Functionally, the loss of the ascent fuel tank would preclude a lunar ascent. This failure would result in loss of the crew if it occurs from the non-abort zone in powered descent through the lunar ascent minimum rescue orbit.	RCS Oxid. Tank Sys. A.	Hypergolic mixing	X	X	X	X	X	X	X	Close proximity to fuel. Rupture may result in fire or explosion.
	RCS Fuel and Oxid. lines for Quad #1 or Quad #2.	1) Loss of all RCS capability.				X	X	X	X	Close proximity of redundant systems. Damage upstream of the isolation valves can result in propellant depletion from both RCS systems. Loss of Att. Control.
		2) Hypergolic mixing.	X	X	X	X	X	X	X	Close proximity of oxid. & fuel lines. Rupture of both may result in explosion or fire.
	RCS engine control wiring for Quads #1 and #2.	Loss of attitude Control				X	X	X	X	Close proximity of RCS cables. Loss or RCS engines. Loss of attitude control.
	Cabin	Rapid decompression of cabin.				X	X	X	X	Loss of crew if they are not in the closed suit loop mode.

Table 6.3-1 - Summary Table For Fragmentation Type Failure Effects on the LM Vehicle (Cont'd

Tank and Functional Concern	Surrounding Safety Hazard Equipment	Major Additional Concern	Crit. Mission Phase							Remarks
			1	2	3	4	5	6	7	
All tanks in Quad 3 (i.e. SHe, GHe, GOX) Loss of the fluids in any or all of these tanks is not crew safety (Loss of mission only).	Any one or all tanks in Quad #3, fuel tank (+Y), Oxid tank (-Z)	Fragmentation	X	X	X	X	X			May cause chain reaction of high pressure tank bursts and/ or cabin rupture.
	Descent Engine Fuel & Oxid. line (lower deck quad 3)	Hypergolic mixing	X	X	X	X	X			Close proximity of oxid. and fuel lines. Rupture of both may result in explosion or fire.
	Fuel Tank (+Y) or Oxid Tank (-Z) or Fuel manifold or (lower deck Quad #3) Oxid. Manifold (lower deck Quad #3)	Loss of descent engine capability.				X				Explosive ruptureof this tank (line) causes shutdown of descent engine. This failure causes loss of crew in non-abort stage zone.
	ED nut & bolt comb. (Quad #3)	Nut & bolt firing lines severed.				X	X			Close proximity of cables from redundant ED systems. Inability to stage vehicle.
	RCS Engine lines (Sys. A&B) (Oxid. and Fuel)	Loss of both RCS systems.				X	X			Close proximity of redundant systems. Damage upstream of isolation valves. Loss of all RCS fuel or oxid. Loss of Att. Control capability.
		Hypergolic mixing	X	X	X	X	X			Close proximity of oxid. & fuel lines. Rupture of both may result in explosion or fire.

Table 6.3-1 - Summary Table For Fragmentation Type Failure Effects on the LM Vehicle (Cont'd)

Tank and Functional Concern	Surrounding Safety Hazard Equipment	Major Additional Concern	Crit. Mission Phase 1	2	3	4	5	6	7	Remarks
Descent Water Tank (Quad #2) If the only failure was leakage of all the H_2O in this tank it would have no effect on crew safety at any time in the mission.	Descent engine fuel manifold (Quad #2) or DPS fuel tank (-Y) or DPS Oxid Tank (-Z).	Loss of descent engine capability				X				Explosive rupture of this line or tank causes shutdown of descent engine. This failure causes loss of crew in non-abort stage zone.
	DPS Fuel Tank (-Y) or DPS Oxid. Tank (-Z)	Explosive Rupture	X	X	X	X	X			May cause chain reaction of high pressure tank bursts and/or cabin rupture.
	RCS Engine lines (Sys. A&B) (Oxid.& Fuel)	Loss of both RCS Systems				X	X			Close proximity of redundant systems. Damage upstream of isolation valves would cause loss of all RCS fuel or oxid. loss of attitude control.
		Hypergolic mixing	X	X	X	X	X			Rupture of both may cause an explosion or fire.

Table 6.3-1 - Summary Table For Fragmentation Type Failure Effects on the LM Vehicle (Cont'd)

Tank and Functional Concern	Surrounding Safety Hazard Equipment	Major Additional Concern	Crit. Mission Phase							Remarks
			1	2	3	4	5	6	7	
Descent GOX Tank (LM-10 only) (Quad #4)	Descent Water Tank No. 2 (Quad #4) or GOX Tank (Quad 4)	Explosive rupture.	X	X	X	X	X			Close proximity to descent fuel or oxid tanks which has high TNT equivalent.
If the only failure was leakage of all GOX in this tank it would have no effect on crew safety or any time in the mission or Descent Water Tank (quad 4)	Ascent H_2O Tank	Explosive rupture.	X	X	X	X	X			Close proximity to descent fuel or oxid tanks which has high TNT equivalent.
	DPS Fuel (+Y) or DPS Oxid (+Z) Tank(s)	Explosive rupture	X	X	X	X	X			May cause chain reaction of high pressure tank bursts and/or cabin rupture.
	ED Relay Box and Wiring or Umbilical Cutter	Inadvertent cable cutting (Loss of all LM power).				X	X			See LED-550-175B for complete discussion of effects of inadvertent cable cutting. It should be noted that if the ED Relay Box were the cause it would require the transfer of 3 relays.
	Umbilical Cutter or ED Nut and Bolt Combination (Quad #2)	Staging				X	X			Close proximity of redundant ED wiring.
	Wiring	Eletrical Shorts	X	X	X	X	X			Eletrical shorts in an oxygen environment could result in a fire.

Table 6.3-1 - Summary Table For Fragmentation Type Failure Effects on the LM Vehicle (Cont'd)

Tank and Functional Concern	Surrounding Safety Hazard Equipment	Major Additional Concern	Crit. Mission Phase 1	2	3	4	5	6	7	Remarks
Descent GOX Tank (LM-10 only) (Quad #4)(Cont'd)	RCS engine lines (Sys, A&B) (Oxid. and Fuel).	Loss of both RCS systems.				X	[illegible]			Close proximity of redundant systems. Damage upstream of isolation valves would cause loss of all RCS fuel or oxid. and loss of attitude control capability.
		Hypergolic mixing	X	X	X	X	X			
	Cabin	Rapid decompression				X	X			Loss of crew if they are not in closed suit loop mode.

6.4 THERMAL BLANKET PROTECTION

The loss of thermal blanket insulation prior to LM activation and the resultant possibility of high solar heat inputs is of particular concern for the subsystems listed below:

- o Propulsion Subsystem
- o Reaction Control Subsystem
- o Environmental Control Subsystem.

This section presents the results of an investigation of the thermal problems associated with the LM tanks, if the thermal insulation should be damaged or removed. Temperature and pressure response of the tanks are presented with comments on the possible cause of insulation damage.

The following basic areas were analyzed:

- o Determine which tanks could explode during translunar coast due to loss of thermal shielding
- o Evaluate the potential of losing the thermal shield in such a way that the crew would be unaware of the loss (LM not powered up) from such causes as:
  - -Propellant spill
  - -SLA withdrawal
  - -CSM RCS Impingement
  - -Launch
- o Evaluate whether hardware or procedures should be changed as a result of the above studies.

6.4.1 Thermal Analysis

A simplified analysis of each of the LM tanks was performed assuming that the blankets and shielding surrounding the tank were missing, Figure 6.4-1, exposing each tank to direct solar energy and cold deep space. Figure 6.4-2 presents the configuration assumed for the APS and DPS propellant tanks. Table 6.4-1 indicates the properties assumed and nodal network used for each case. Note, the solar absorptivity has never been measured on any of the LM tanks, therefore the values were taken from the literature or were assumed. To obtain the thermal response of a tank, the analysis assumed that the solar vector impinges directly on a tank for 4 hours followed by 4 hours of deep space cooling. The LM Thermal Design

6.4.1 cont'd

Mission limits the vehicle attitude hold periods during translunar coast to 3 hours. Figures 6.4-3 through 6.4-12 indicate the temperature and pressure response of the tank skin, gas and bulk fluid for each pressure vessel. The descent stage water tank was excluded from this study because of the presence of a 25-layer insulation blnaket wrapped around the tank.

6.4.2 Potential Loss of Thermal Shielding

The thermal shielding is made up of many individual blankets that are interconnected with "drugstore" wraps. Therefore, it is not possible to lose the thermal protection from any single area, such as a descent stage quadrant, through loss of a single panel. The most likely damage mode, if any, would be for a "drugstore" wrap to open. In addition, since the blankets are made up of multi-layered material, it is possible to get tears in the outer layers without significantly degrading the thermal protection. All the thermal shielding is inspected during the pre-launch SLA activities,and a final inspection is made just prior to SLA close-out. Because of this thermal blanket configuration and these procedures, it is not a realistic possibility that significant areas could be lost or degraded during the launch-and-boost or transposition-and-docking phases.

6.4.2.1 Propellant Spill

LM thermal blankets would be permanently damaged if propellant (liquid or vapor) spilled on them. The blanket failure consists of two modes:

- The aluminum is removed from the H-film (or mylar) substrate layer, thus exposing a transparent high emittance layer
- The blanket layers adhere to one another and the multilayer radiation barrier becomes a single conductive layer which acts as a thermal short.

A failure due to propellant spill in areas with H-film as the external shield (descent stage) would be as severe as losing the complete thermal shielding, because of the "greenhouse effects" of the transparent blankets.'

Solar energy would be transmitted directly through the blanket into the tank, while the remaining blanket would be an infrared shield to cold deep space. Those areas of the LM which do not have H-film as the outer blanket would not be as severely affected because there would be no "greenhouse effect".

6.4.2.2 SLA Withdrawal

It is geometrically impossible to damage the primary descent stage thermal blankets during SLA withdrawal. However, it is possible to catch and tear insulation from the landing gear lower outriggers, if the SLA withdrawal angles are exceeded. Failure of this nature is not critical for the tanks, but the landing gear would be affected during powered descent (F.U.T. heating); the lower outrigger critical temperature is +300°F.

6.4.2.3 RCS Impingement

RCS plume impingement is a design consideration for the thermal blankets. The present LM design criteria are summarized below:

Engine	Configuration	Time-sec	Duty Cycle %
SM RCS	CSM/SIVB (Separated)	5	100
	(Docked)	7	100
LM RCS	Staged and Unstaged	30	100
(Up Firing)			
LM RCS	Staged	85	100
(Down Firing)	Unstaged	120	40

If the design capability is exceeded, the thermal blanket effectiveness will be degraded. The degradation, however, will never be as severe as completely losing the thermal shielding.

6.4.2.4 Launch Vibration

The LM thermal shielding is not critical for the launch shock and vibration loads. This was demonstrated during the LTA-3 launch test of Quad I.

6.4.2.5 Explosion

The thermal shielding could be damaged from a tank failure or rupture of the descent stage GOX tank burst disc. If this occurred, the internal components would be exposed to space and possibly direct sunlight. This represents the most critical failure mode of the thermal blankets, and could lead to solar heating as discussed in Para. 6.4.1.

6.4.2.6 Thermal Shielding Vents

The table below summarizes the LM venting configuration for the ascent and descent

6.4.2.6 cont'd

stages. The $\triangle$P(limit) is the pressure differential design point for boost venting, and the $\triangle$P(ultimate) is the pressure differential that will cause insulation damage.

	LM-8 D/S	LM-10 D/S	LM-8 & -10 A/S
Total No. of Vents	8	3 large & 4 small	22
Available Vent Area - sq. in.	160	154	78.5
$\triangle$ P (limit) - psia	.02	.02	.0278
$\triangle$ P (ultimate) - psia	.03	.03	.0415
Vent Area (limit) - psia	114	105	69.5
Vent Area (ultimate) - sq. in.	90	82.5	54
No. of Vents That Must Be Lost To Reach Limit	3	1 large or 2 small	3
No. Of Vents That Must Be Lost To Damage Insulation	4	2 large or 3 small	7

The LM-8 and LM-10 venting requirements for the descent stage are both presented because of the LM-10 design modifications. Expressed as precentages, the following vent areas must be inoperative before insulation damage occurs:

- o LM-8 Descent Stage - 37.5% of total vent area
- o LM-10 Descent Stage - 34% of total vent area
- o LM-8 & -10 Ascent Stage - 27% of total vent area.

6.4.3 Tank Fracture Mechanics

Figures 6.4-13 through 6.4-21 show the degradation in pressure capability as tanks are heated after thermal blanket loss. Each curve is a stress/pressure versus temperature plot showing material strength degradation. A $1\frac{1}{2}$ factor-of-safety curve is also presented. This factor-of-safety curve shows the stress/pressure not to be exceeded by design when pressurizing the tank. Superimposed on this graph is a plot of the increase in pressure that would occur during a 4-hour attitude hold with the thermal blanket degraded as described in Para. 6.4.1. It should be noted that for a given propellant tank the highest pressure was used (oxidizer or fuel). Table 6.4-2 summarizes those attitude-hold times, less than 4 hr, required to increase the stress/pressure in the LM

6.4.3 cont'd

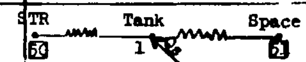
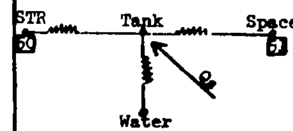
pressure vessels from NOP to MDOP (factor of safety = 1.5) and NOP to design burst pressure (factor of safety = 1.0).

6.4.4 Potential Changes

The following procedural and hardware changes would reduce the criticality of the loss or degradation of the LM thermal shielding:

- o Visually inspect the LM during transposition and docking to ensure that all LM thermal shielding is in place
- o Monitor LM telemetry during translunar coast; presently no LM measurements are available during unmanned mission phases
- o Measure solar absorptivity of all pressure vessels to accurately predict the thermal response of the tanks
- o Insulate all tanks with a layer of H-film; this will significantly reduce the amount of solar energy that can be absorbed by each tank in direct sunlight; a single layer will not adversely affect the vehicle thermal network.

TABLE 6.4-1 THERMAL PROPERTIES AND ASSUMPTIONS

TANK	TANK MATERIAL	TANK DIAMETER (INCHES)	TANK WEIGHT (LBS)	FLUID WEIGHT (LBS)	α_s	ϵ_{th}	VIEW TO SPACE	VIEW TO STRUC	NODAL NETWORK
D/S Ambient He	Titanium	15	10	1	.6	.12	.2	.8	
D/S ECS Oxygen	Steel-D6AC (Cadmium plated; painted with black epoxy)	21.25	59	48	.85	*.85	.2	.8	Same as D/S He Tank
D/S SHe (outer shell temperature only)	Titanium	32.9	74.3	-	.6	.12	.2	.8	Same as D/S He Tank
A/S Water (D/S Water Tank is completely insulated see text)	Aluminum	14.6	5.2	42	.86	.86	.2	.8	
A/S APS He	Titanium	22.48	55.6	6.5	.8	*.4	.2	.8	Same as D/S He Tank
A/S RCS Propellant	Titanium	12.5 (38"high)	12	204	.7	*.15	.2	.8	Same as A/S H_2O Tank
A/S RCS He	Titanium	12.37	9	1	.6	*.12	.2	.8	Same As D/S Amb.He Tk.
A/S GOX	Inconel	11.8	5	2.4	.67	.32	.2	.8	Same as D/S Amb.He Tk.
DPS Propellant (Fuel) (oxidizer)	Titanium	51.25	115.5	3575 5700	.8	.2	0	1.0	See Figure 6.4-2
APS Propellant (Fuel) (oxidizer)	Titanium	49.38	75.2	1960 3150	.8	.2	.5	.5	See Figure 6.4-2

* Measured values
o Iterated nodes
☐ Boundary nodes

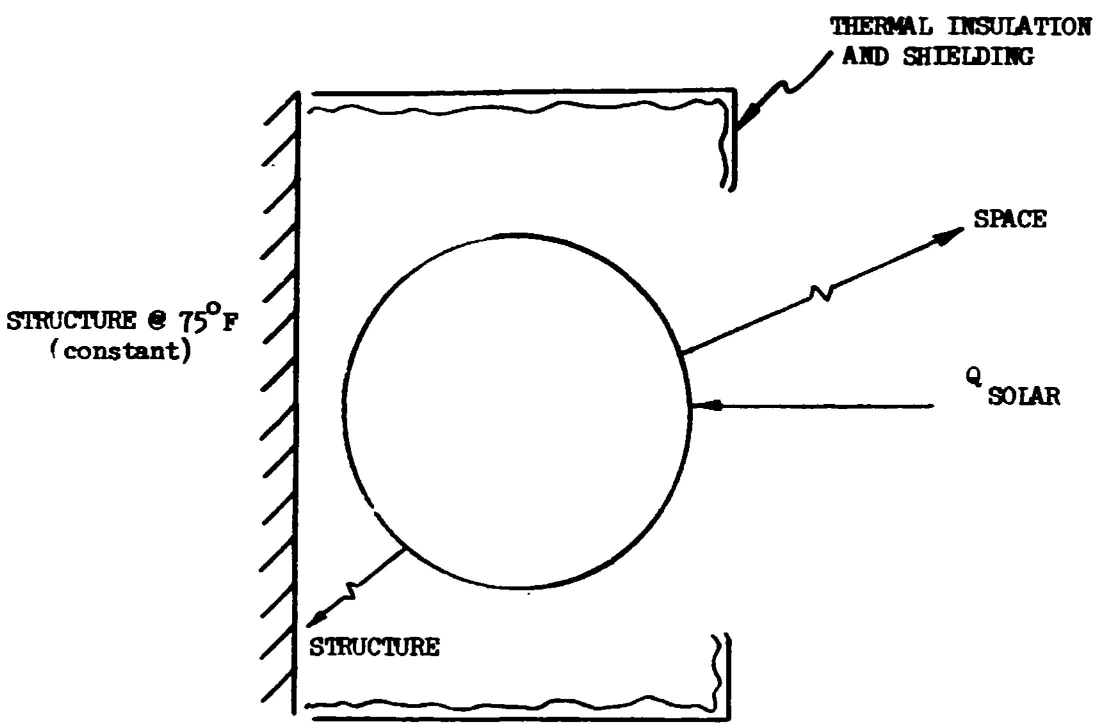
Table 6.4-2

Pressure Rise Times From Solar Heating

Tank	Time (Hrs.) From NOP to MDOP (FS=1.5)	Time (Hrs.) From NOP to Burst (FS=1)
D/S Helium	.38	3.1
D/S GOX	> 4	> 4
A/S H_2O	> 4	> 4
A/S He	1.7	> 4
RCS Ox	> 4	> 4
RCS He	.52	> 4
A/S GOX	> 4	> 4
D/S Fuel	> 4	> 4
A/S Fuel	> 4	> 4

Figure 6.4-1

TANK THERMAL MODEL

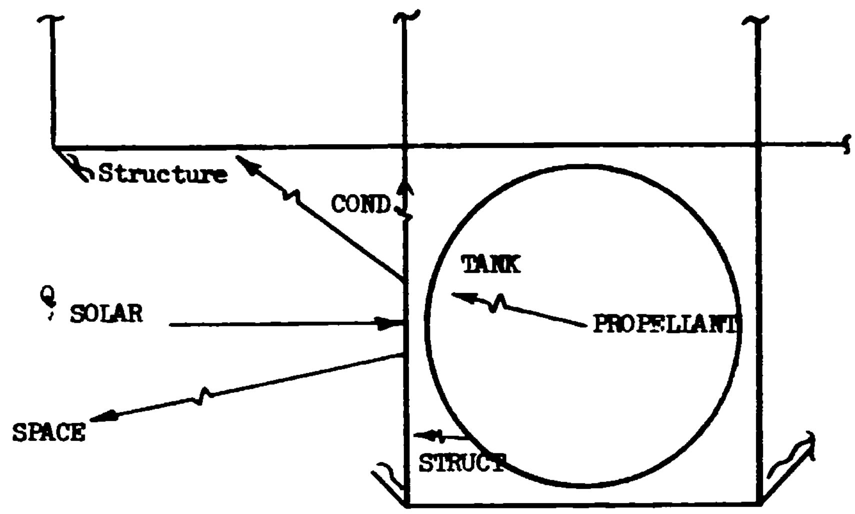


VIEW FACTOR TO SPACE = .2

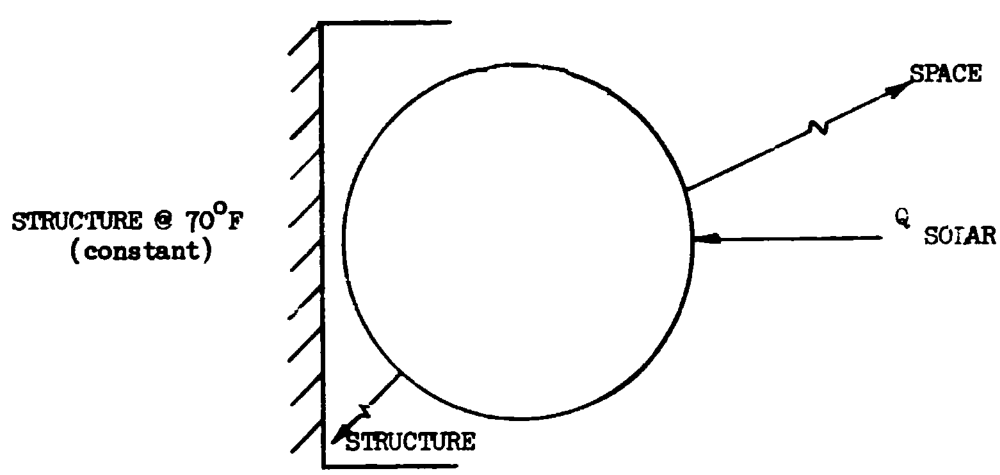
VIEW FACTOR TO LM STRUCTURE = .8

Figure 6.4-2

DPS PROPELLANT TANK THERMAL MODEL



APS PROPELLANT TANK THERMAL MODEL



VIEW FACTOR TO SPACE = .5

VIEW FACTOR TO LM STRUCTURE = .5

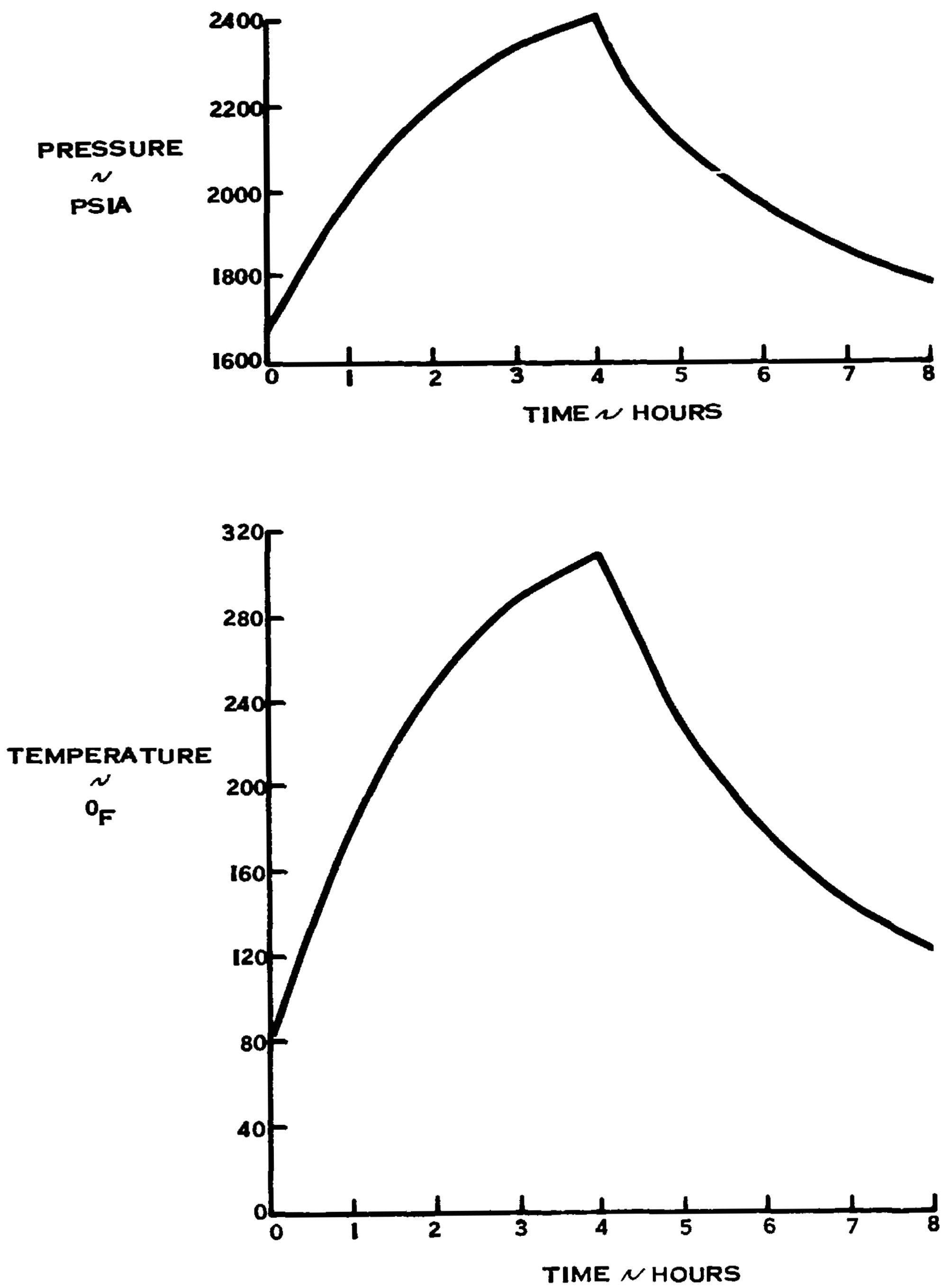


FIGURE 6.4-3. DPS HELIUM TANK

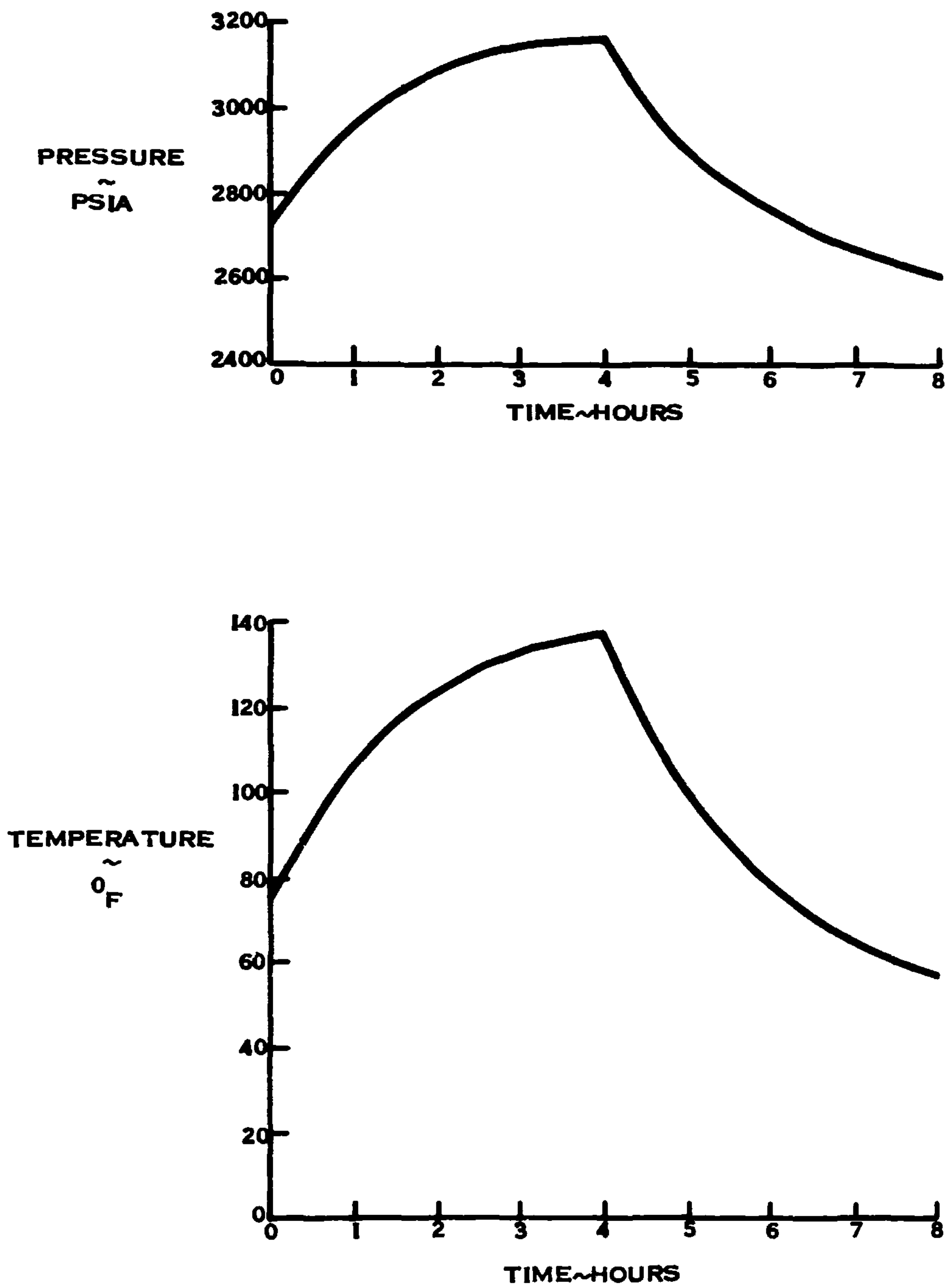


FIGURE 6.4-4. DESCENT O_2 TANK

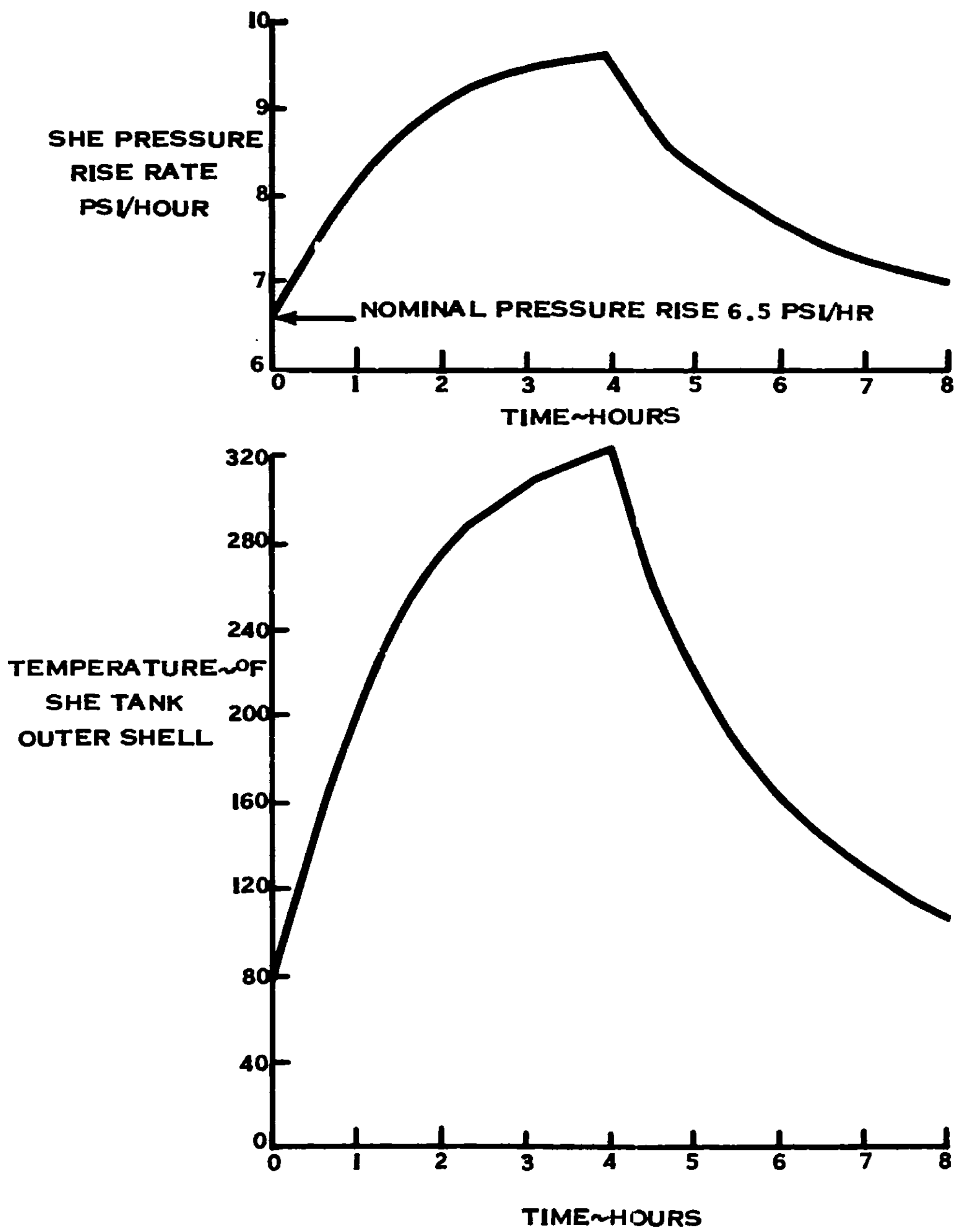


FIGURE 6.4-5. SUPERCRITICAL HELIUM TANK

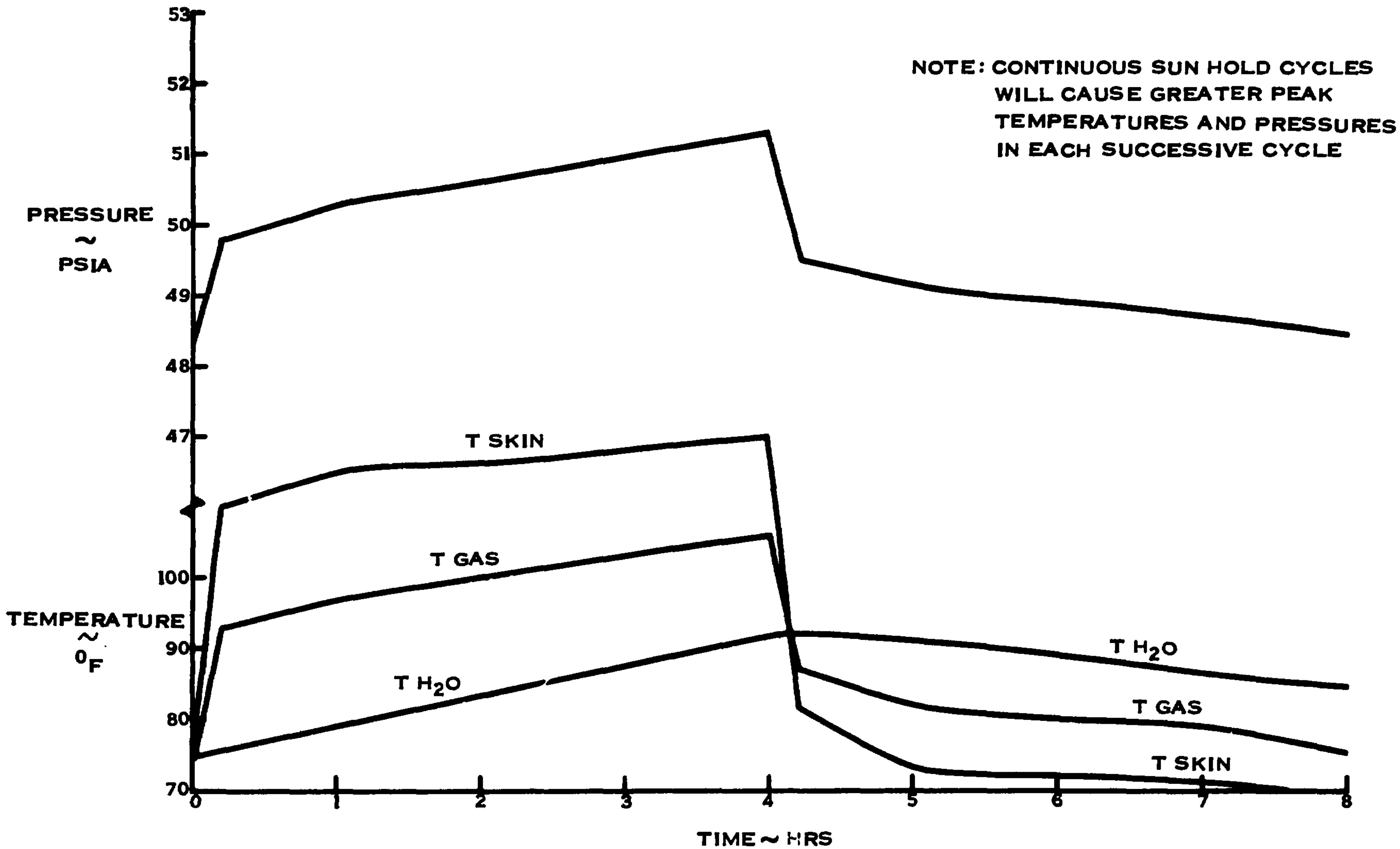


FIGURE 6.4-6. ECS ASCENT H_2O TANK

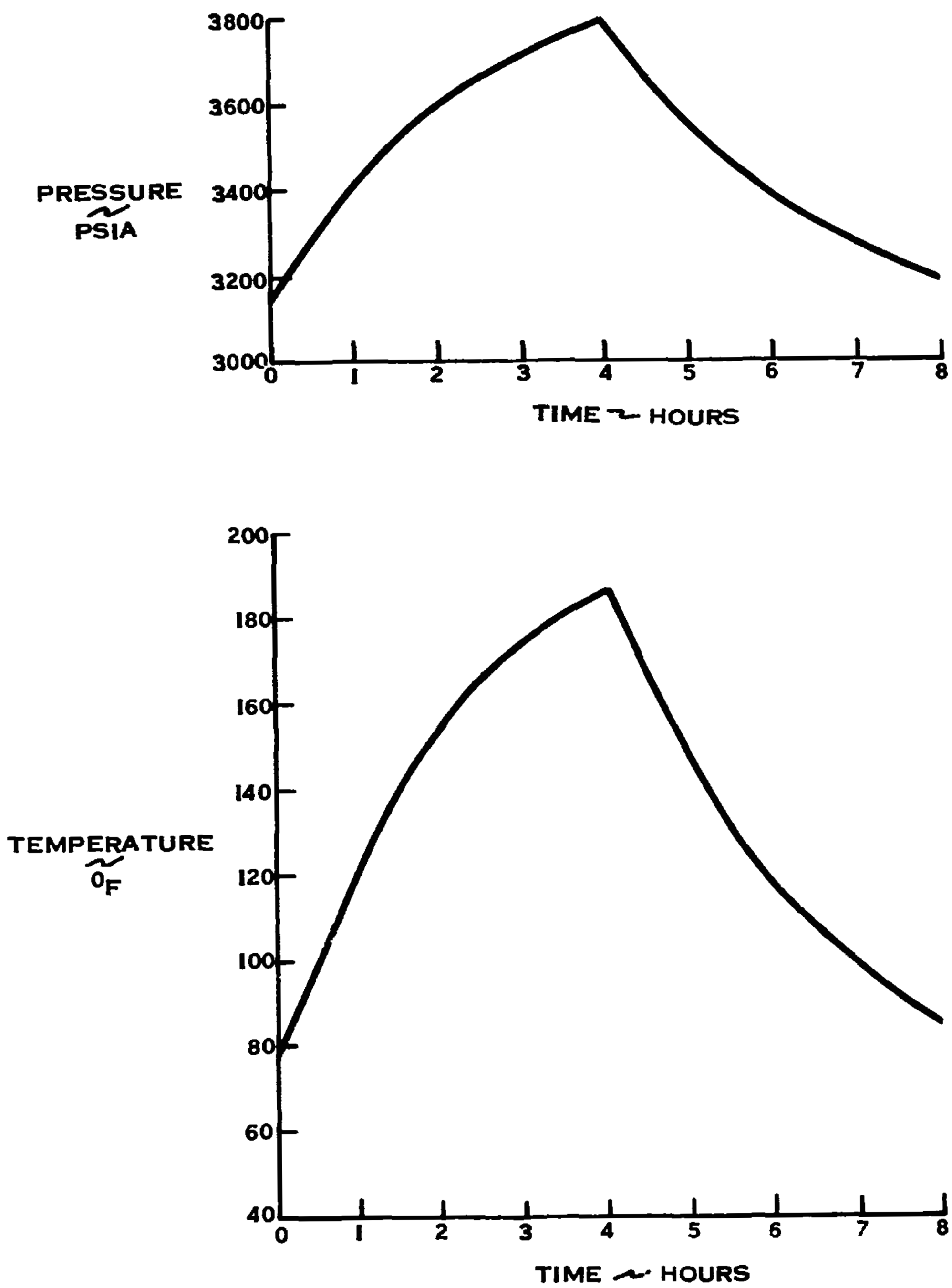


FIGURE 6.4-7. APS HELIUM TANK

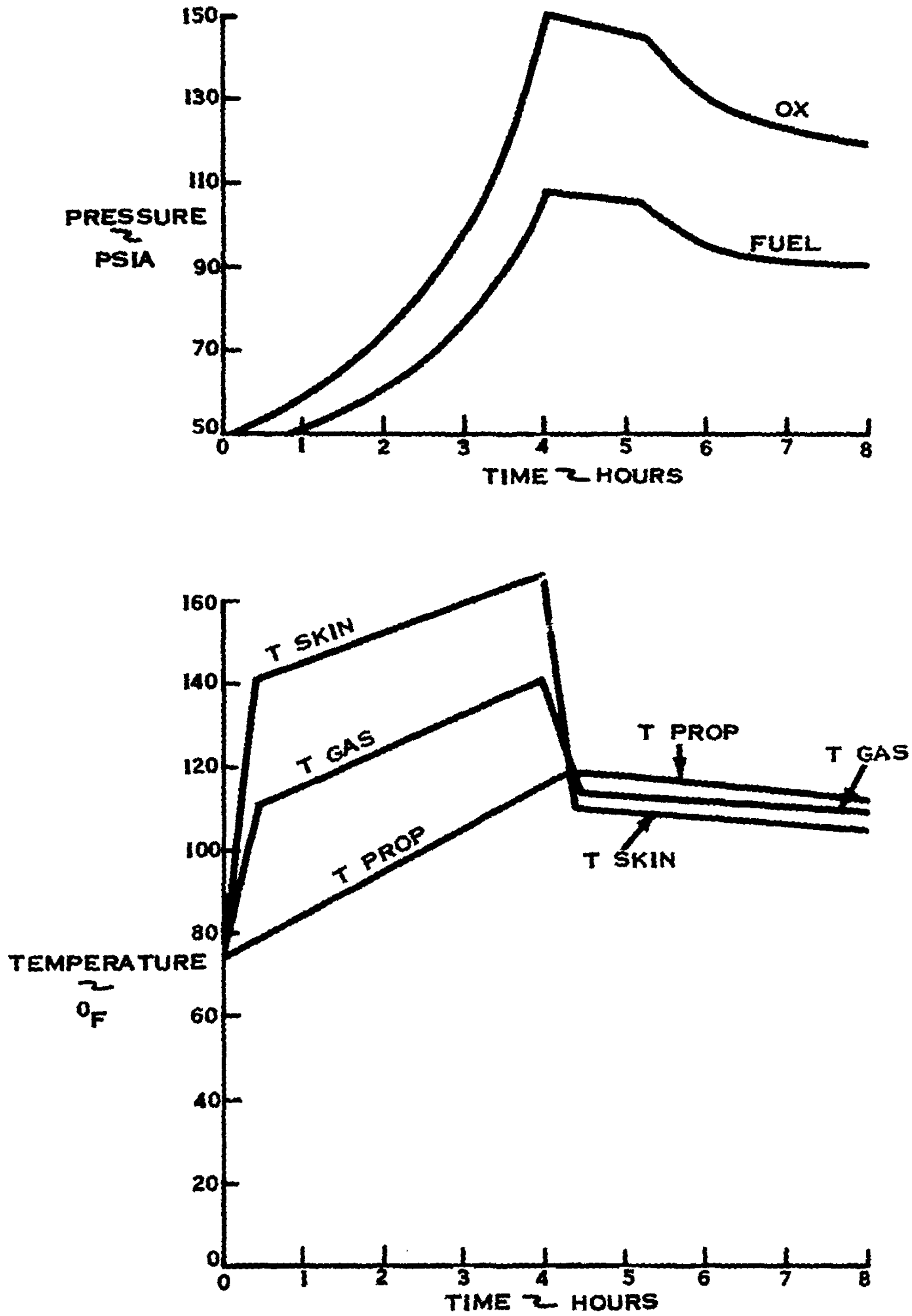


FIGURE 6.4-8. RCS PROPELLANT TANKS

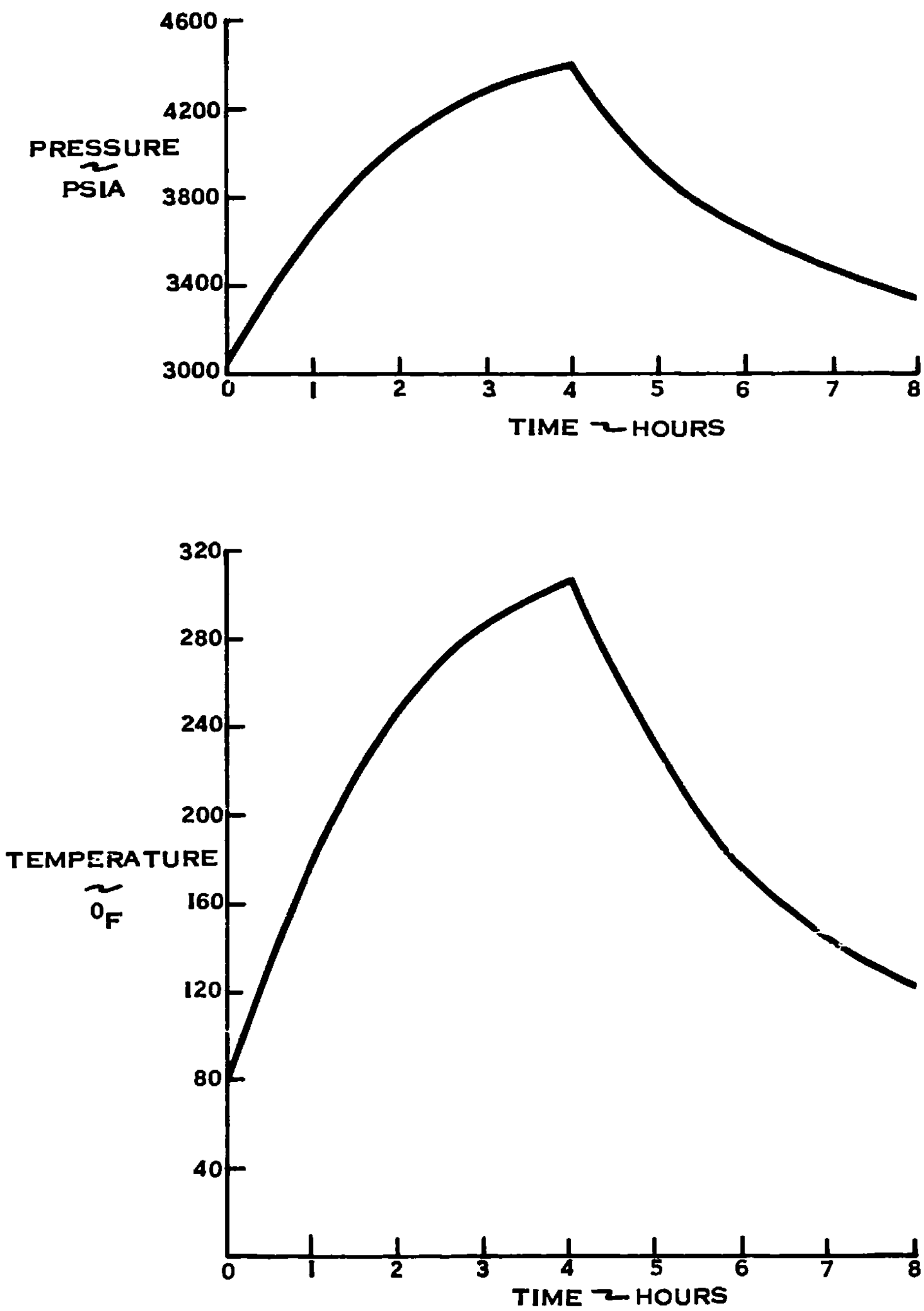


FIGURE 6.4-9. RCS HELIUM TANKS

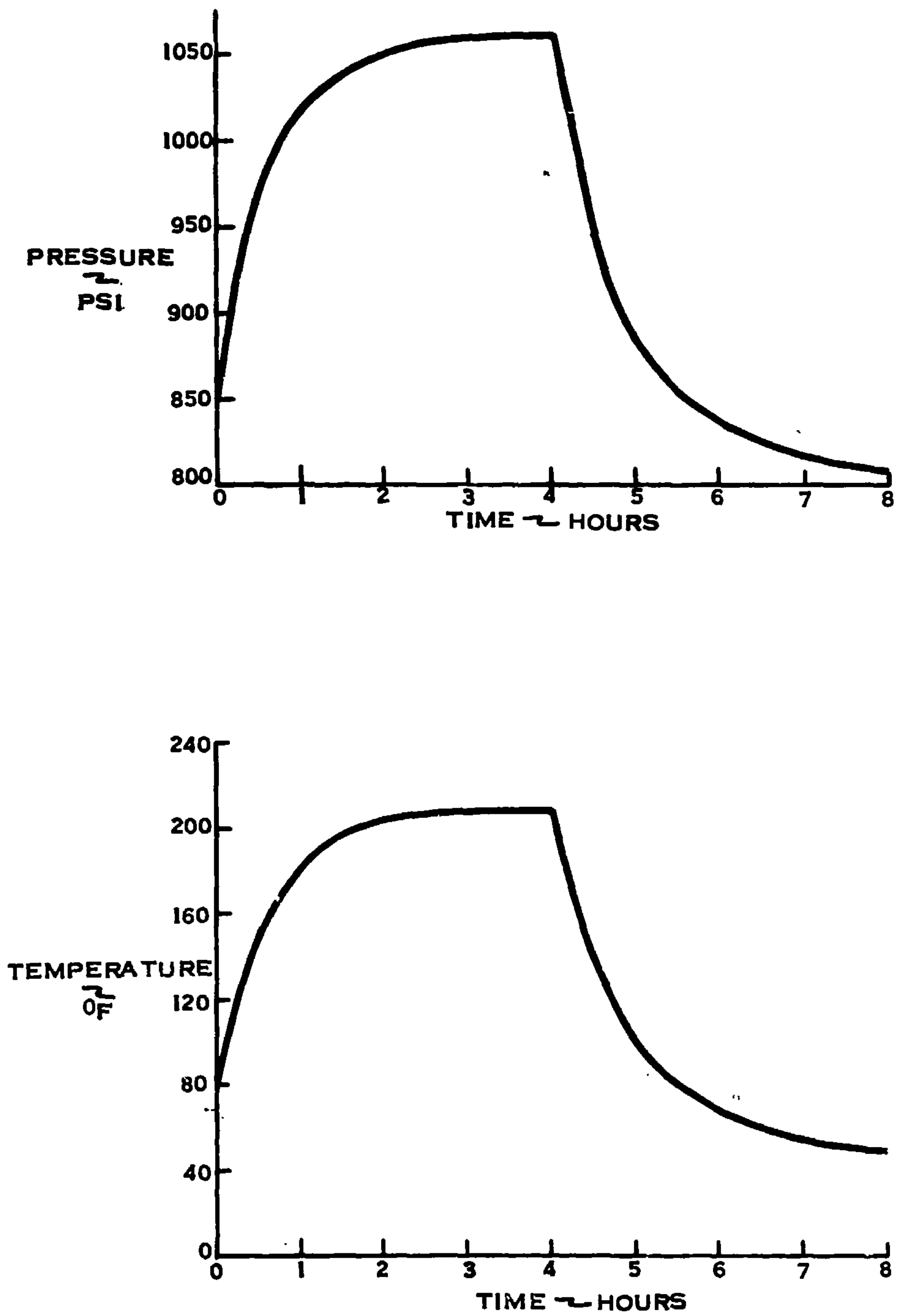


FIGURE 6.4-10. ASCENT O_2 TANK

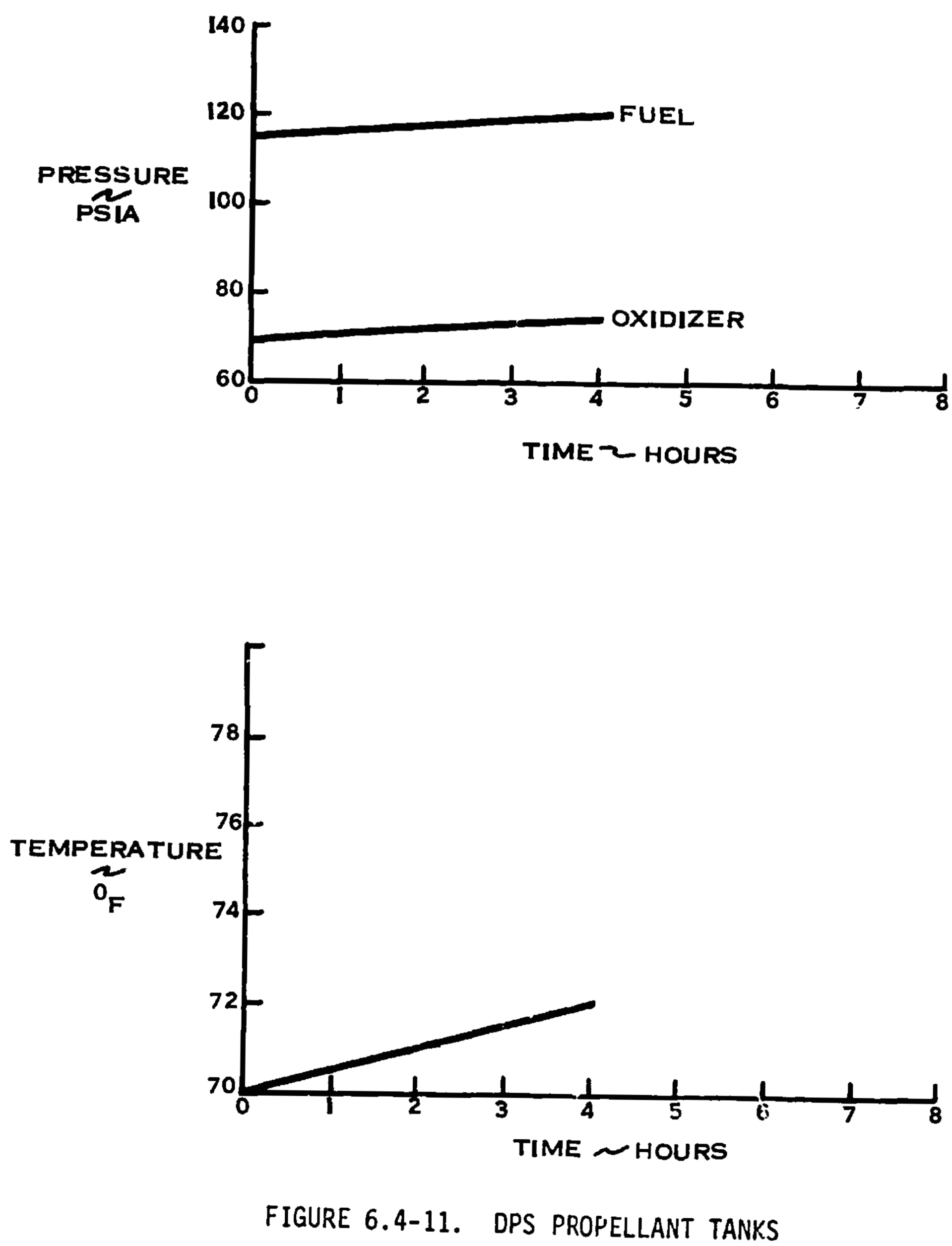


FIGURE 6.4-11. DPS PROPELLANT TANKS

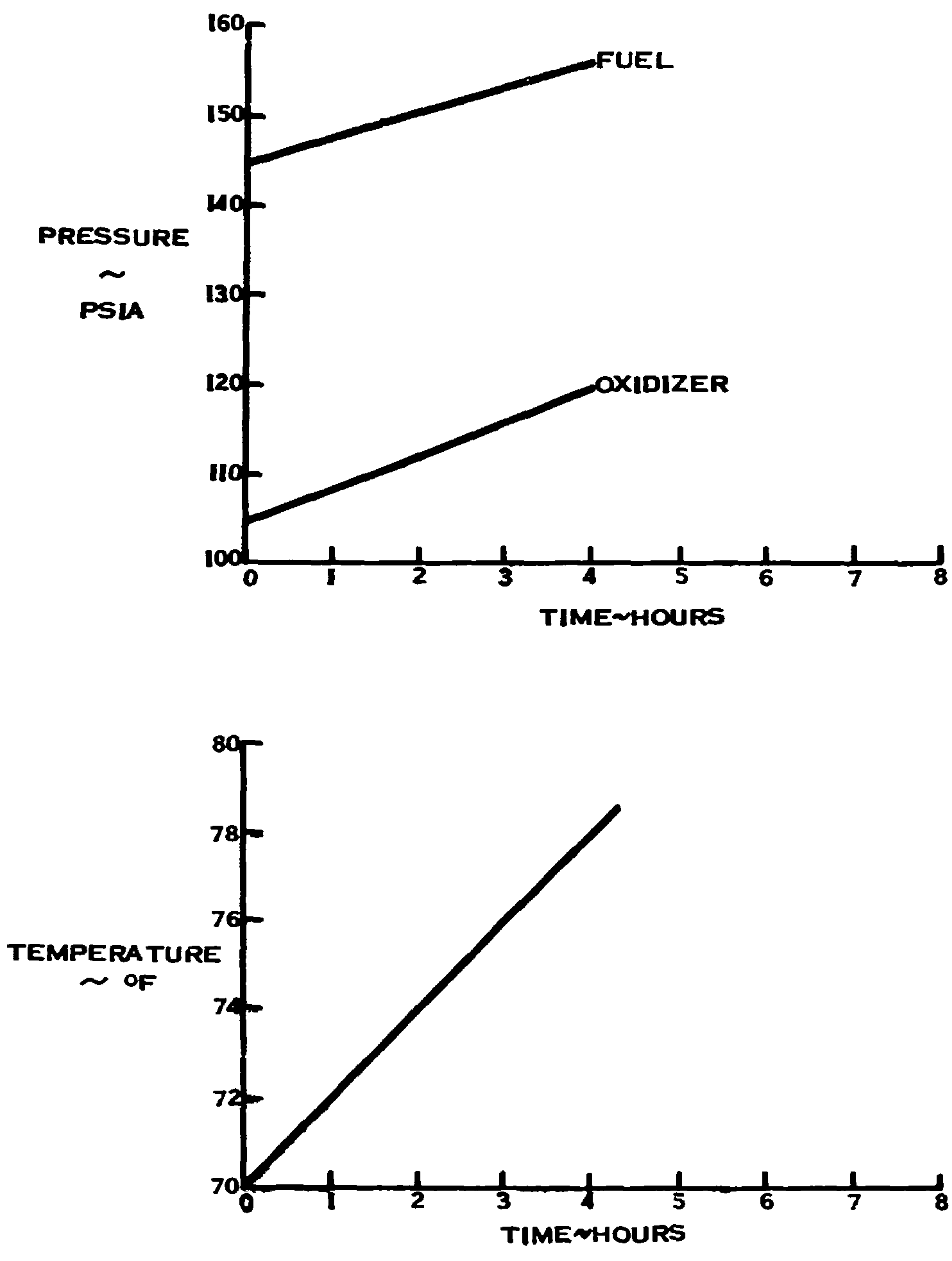


FIGURE 6.4-12. APS PROPELLANT TANKS

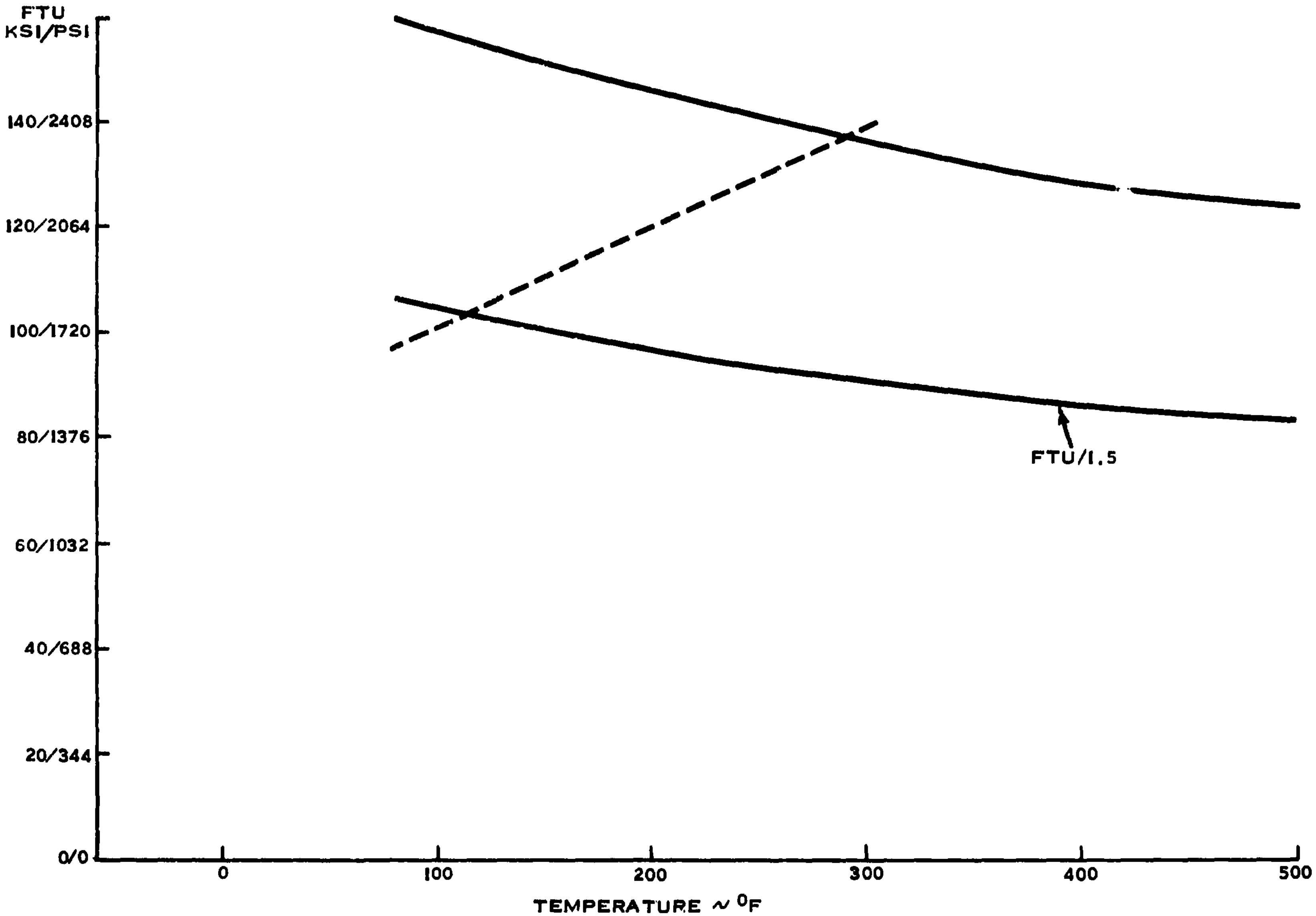


FIGURE 6.4-13. TI 6AI-4V STA, DESCENT STAGE HELIUM TANK

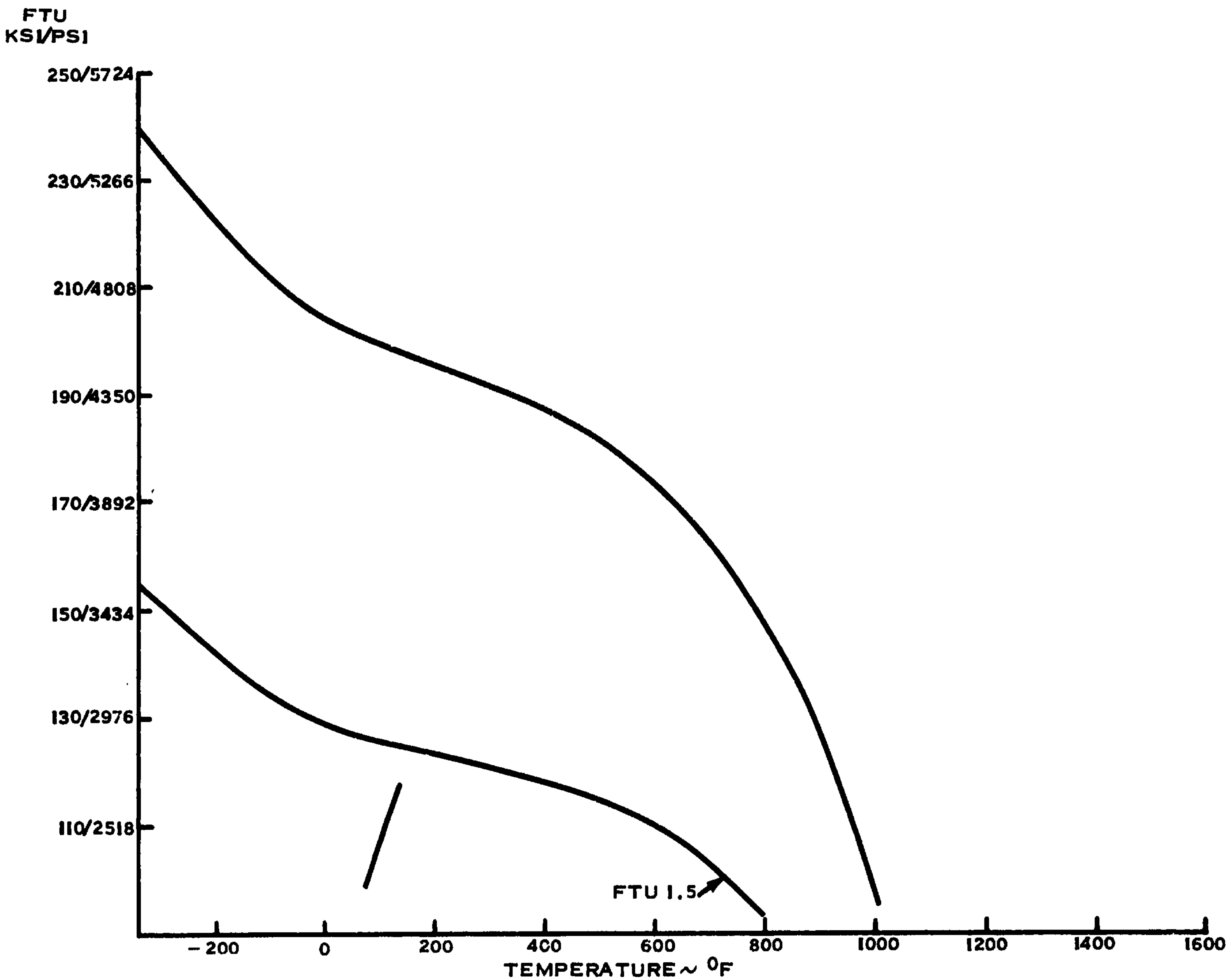


FIGURE 6.4-14. D6 AC, DESCENT STAGE GOX TANK

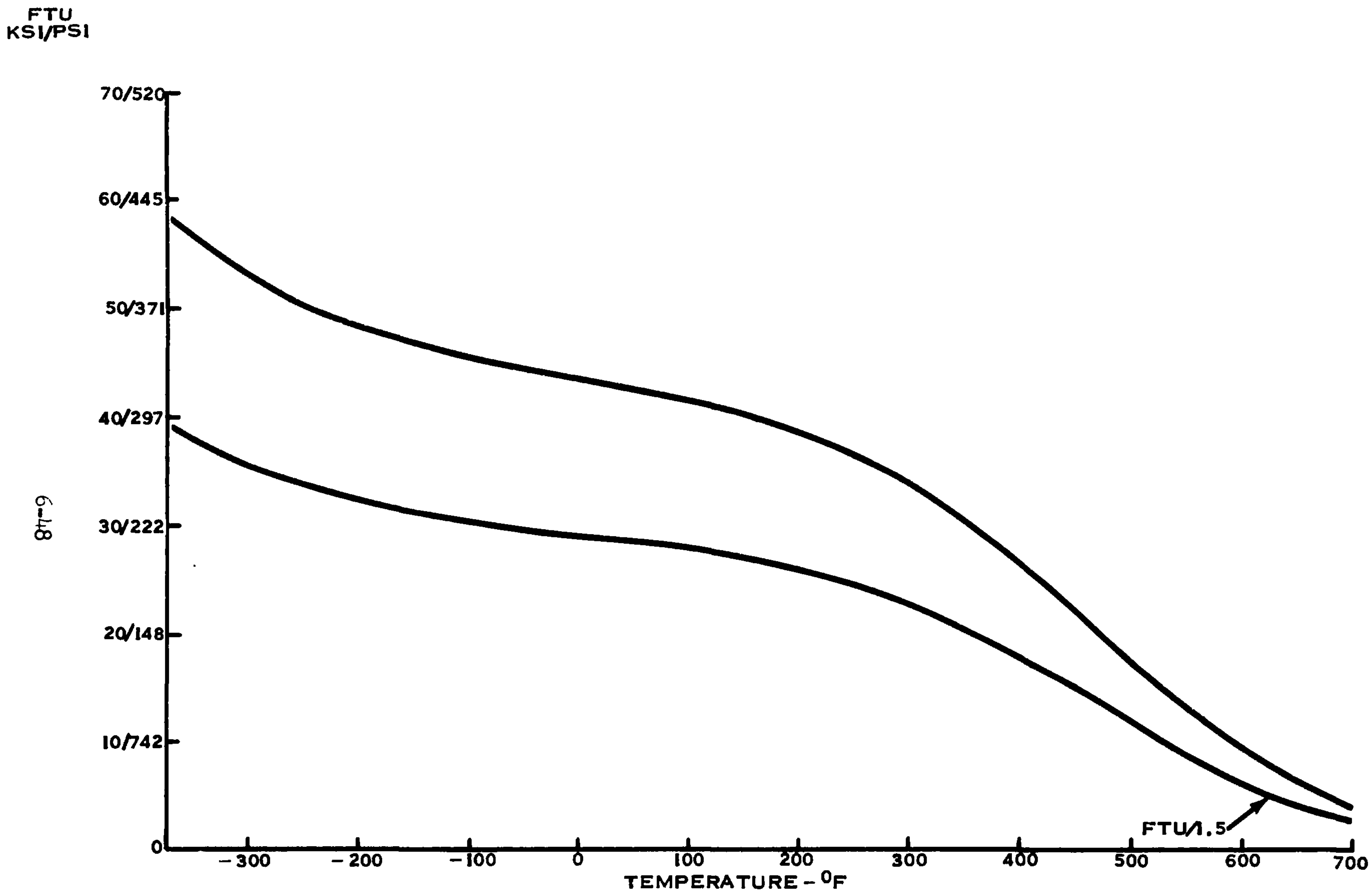


FIGURE 6.4-15. 6061-T6, ASCENT STAGE H_2O TANK

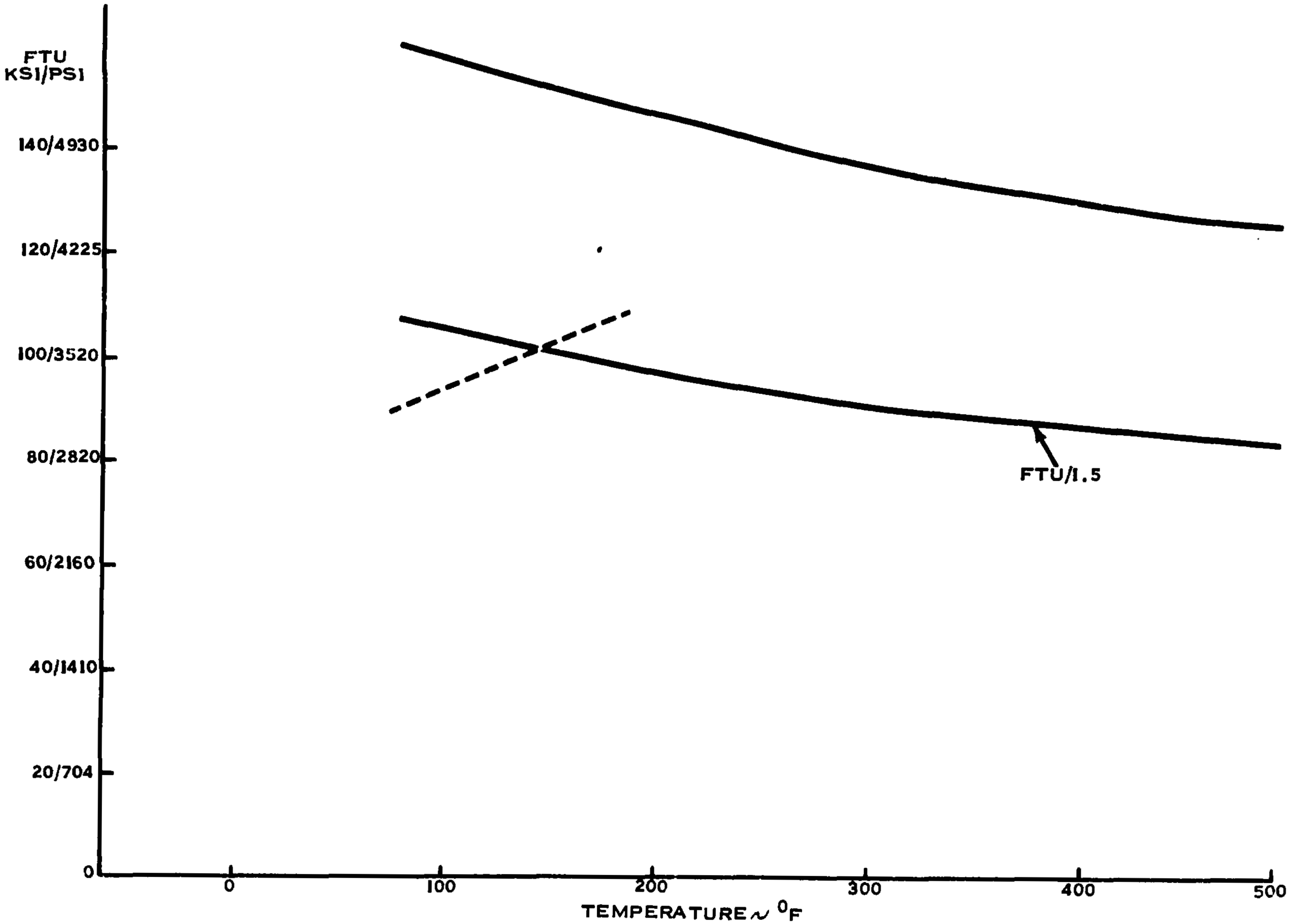


FIGURE 6.4-16. TI 6AI-4V STA, ASCENT STAGE HELIUM TANK

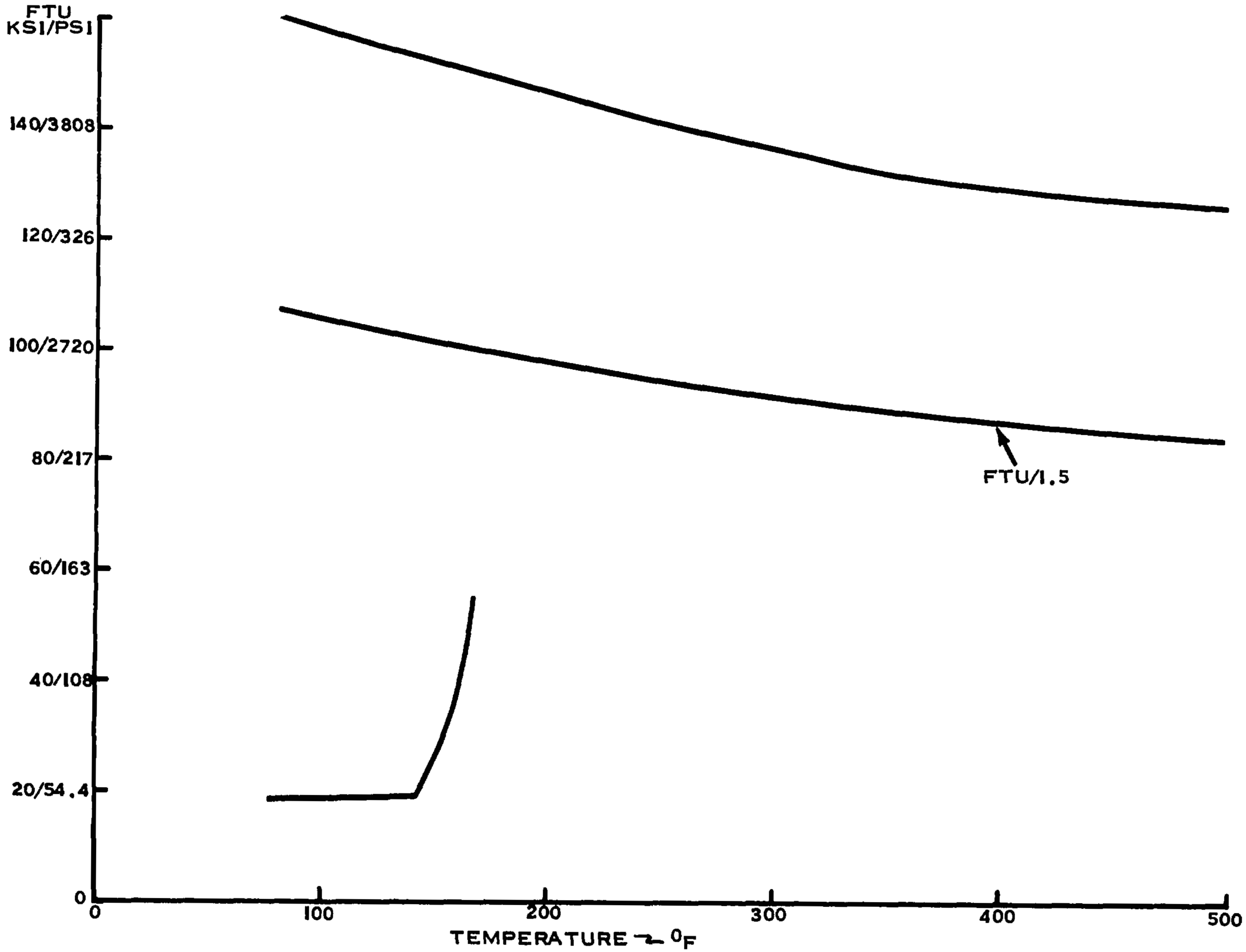


FIGURE 6.4-17. TI 6AI-4V STA, RCS OXIDIZER TANK

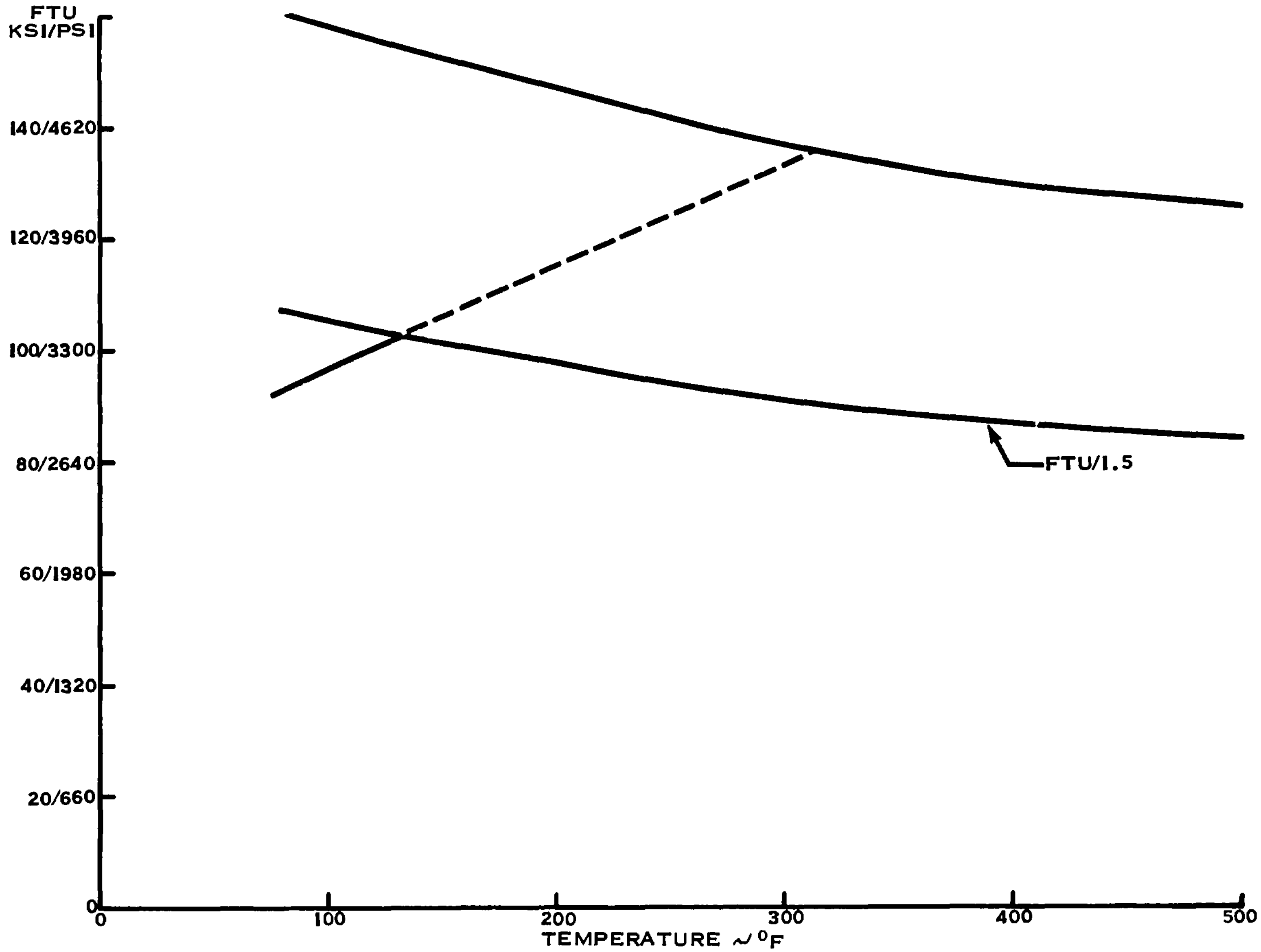


FIGURE 6.4-18. TI 6AI-4V STA, RCS HELIUM TANK

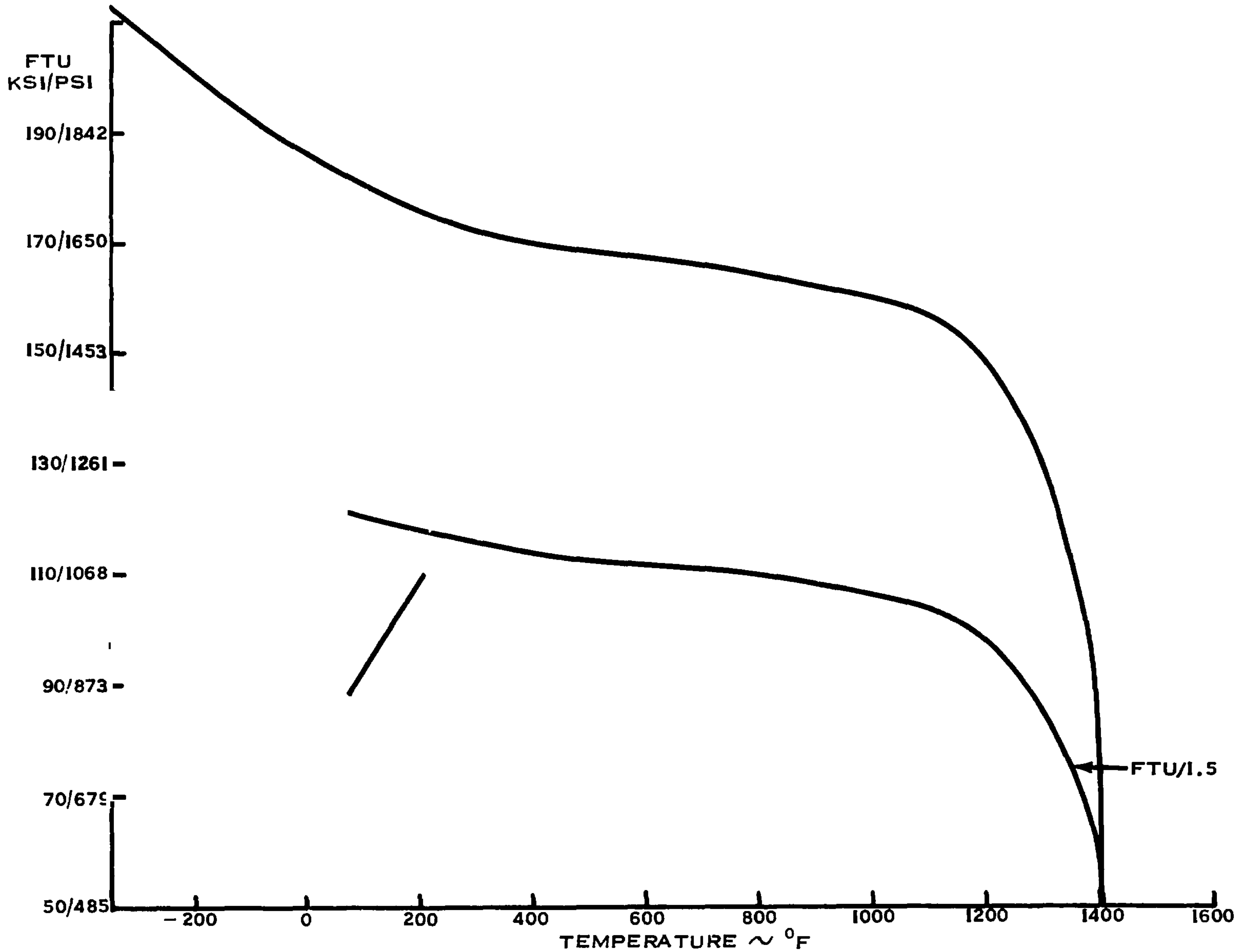


FIGURE 6.4-19. INCONEL 718, ASCENT STAGE GOX TANK

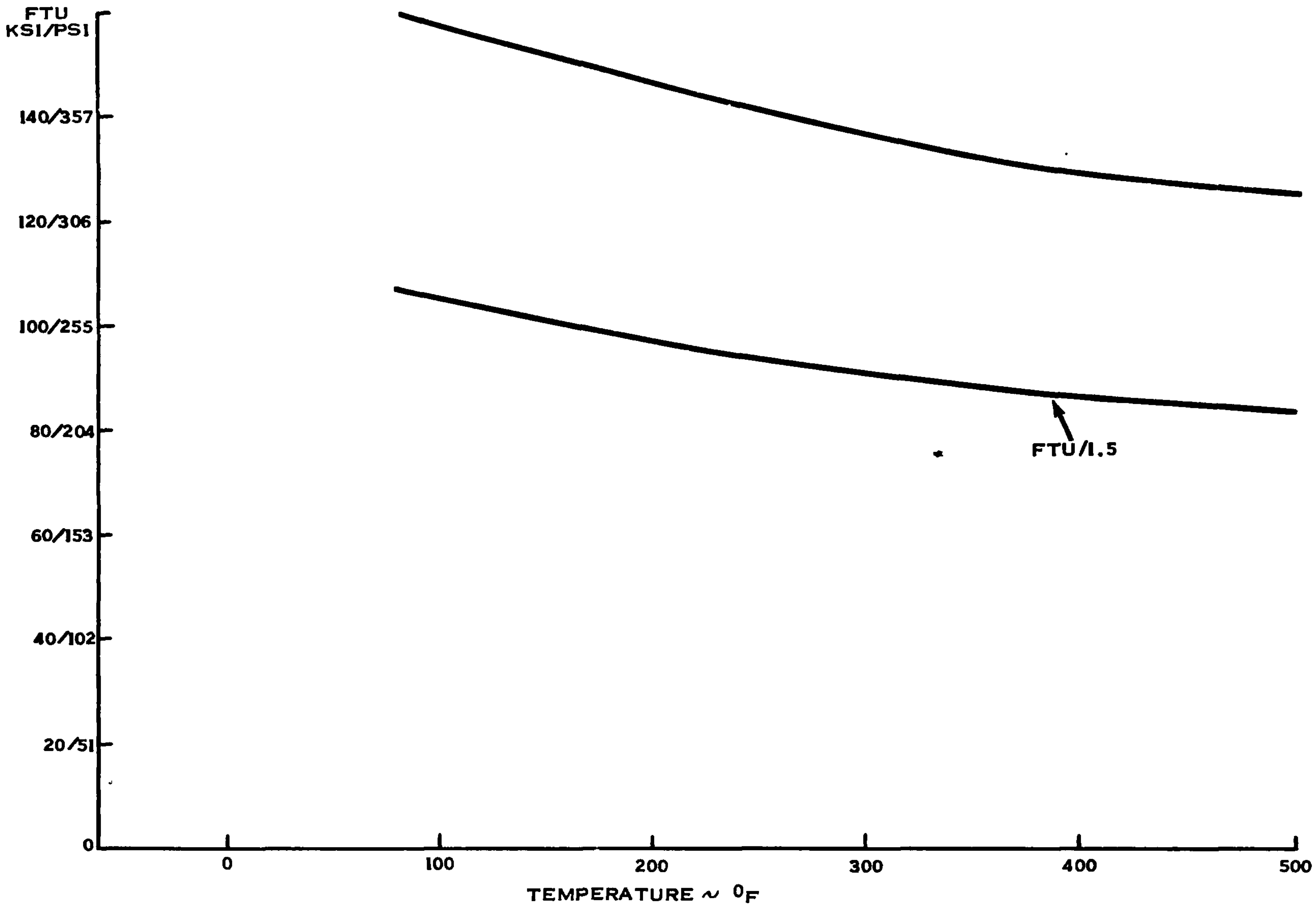


FIGURE 6.4-20. TI 6AI-4V STA, DESCENT STAGE FUEL TANK

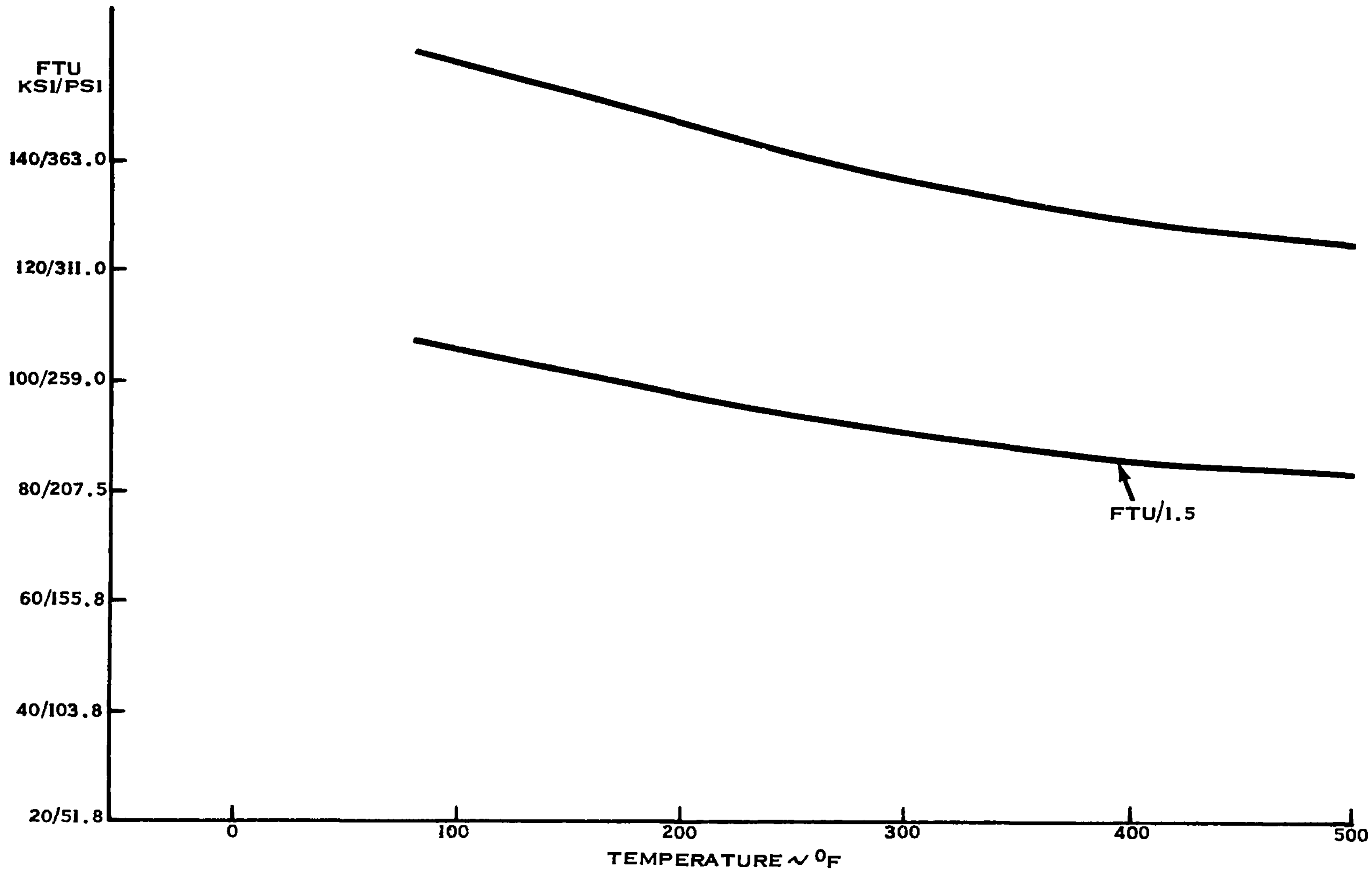


FIGURE 6.4-21. TI 6AI-4V STA, ASCENT STAGE FUEL TANK

7 SUMMARY AND CONCLUSIONS

The objectives of this study were to:

- Identify all possible failure modes in the LM that could lead to rupture of any pressure vessel
- Determine the likelihood of such a failure
- Evaluate the damage potential of such a failure, assuming it did occur

Emphasis was placed on the failure mode that is thought to have occurred in the SM on the Apollo 13 mission; that is, the presence of an ignition source (e.g., electrical short circuit) near a nonmetallic material in an environment that could support combustion. This could then result in a pressure vessel failure (either explosive or non-explosive).

Principal conclusions of the study are as follows:

a. None of the electrical components investigated constitute ignition sources in their normal operating modes. Only the PQGS normally exposes electrical devices directly to the pressurized fluid. After thorough analysis it is concluded that adequate circuit protection is provided to preclude ignition. Tests should be conducted to verify the analysis.

b. The study also included an investigation of the possible effects of a single point failure that could expose internal nonmetallic material and electrical components to the fluid environment.

With respect to materials compatibility, it is concluded that materials in all components, operating in their normal modes, are compatible with their respective fluid environments. For the single point failure modes, there are instances where internal structural failures can expose non-compatible materials to the fluid environment. The primary source of such an occurrence is in transducers. However, records have shown that such a failure mode has never occurred on the LM program in any of the transducers used in the oxygen and propellant systems.

7 cont'd

In the O_2 system mechanical component failures can expose materials to environments for which they are untested. Structural failures must occur before the circuits and materials can be exposed to the fluids. The theoretical factor of safety for these devices is five or greater. They are leak tested at 1.5 times the maximum design operating pressure which is more severe than any other pressure containers. The single point failures not only exposed non-compatible materials, but also exposed them in areas that contained electrical components. A short circuit could then be theorized to represent a potential ignition source. However, analysis indicates all of these electrical circuits have adequate circuit protection devices that will discontinue electrical power before ignition can occur. Tests should be conducted to verify this conclusion.

c. Based on a literature search on the subjects of the capability of oxidizer or fuel to support combustion of the various nonmetallic materials at elevated temperatures, and impact sensitivity of CNR, EPR, and Butyl rubber in oxidizer or fuel, it is concluded that no substantive data are available on either subject. Neither combustion nor impact problems have been encountered in the past. Tests should be conducted to resolve these questions.

d. If ignition and combustion in such devices could occur, the combustion of nonmetallic materials exposed by a single-point failure would increase the local pressure sufficiently to rupture the individual component. This assumes that the initial single-point failure leak path is not large enough to allow expansion into the total system. Even if the pressure increase could expand into the total system, the resultant system pressure could be in excess of burst disc level.

e. Based on a review of the normal operating modes of the various high-pressure systems, it is concluded that the LM pressure vessels are protected with adequate redundancy against failures of such mechanical components as pressure regulators, check valves, relief valves and burst discs. In addition, all of the high pressure systems in the LM are designed with adequate structural factors of safety.

7 cont'd

f. Since there are no electrical components in the LM pressure vessel systems that intentionally, or can accidently, increase tank pressures significantly, the only realistic failure mechanism would appear to be the loss or degradation of thermal blankets. Such a failure could expose the tanks to direct solar heating. However, analysis has shown that relatively short periods of attitude hold are required (e.g., $\frac{1}{2}$-2 hours) to obtain a hazardous pressure and temperature increase in the gaseous He tanks. All other tanks remain within design limits for attitude hold periods up to 4 hours. Wrapping of the gaseous He tanks with H-film would reduce the absorption of solar energy such that attitude holds of at least 4 hours would be permissable. If the LM were manned, then such a failure would be detected and corrective action could be taken. The period of most concern is translunar coast, when the LM is unmanned and unmonitored. However, a passive thermal control mode (slow rotation) is normally employed during this mission phase which results in alternate intervals of solar heating and deep space cooling. Extended attitude holds are possible during this phase. The LM specification requires the vehicle to be capable of continuous attitude holds up to 3 hours duration.

The probability of undetected thermal blanket loss has been investigated, resulting in the conclusion that loss or degradation of significant blanket area is not a realistic possibility in view of the fastening techniques and forces available during the various mission phases (e.g., launch and boost, SLA deployment and ejection).

g. An oxygen leak on LM exterior materials is not considered to be a problem, since the insulation blankets and micrometeoroid shield will only maintain a pressure of less than 0.1 psi without rupturing. Combustion would not be supported at such a low pressure.

h. The entire LM has not been designed to be compatible with N_2O_4 or A-50. If an oxidizer or A-50 tank were to leak or spill its contents, many non-compatible materials would be exposed. The LM is leak checked before a mission to an extremely tight specification; therefore, tankage leaks should not exist for a normal mission.

7 cont'd

i. The study of KOH spillage concluded that only aluminum of the metallic materials has shown a tendency to corrode. The space environment should preclude even the aluminum reaction, because of rapid vaporization of the water from the electrolyte and its subsequent freezing. One possible area of concern is the fracture mechanics stress corrosion effects of a KOH spill on a highly stressed pressure vessel, such as a gaseous helium bottle. No information is available on this subject. Addition of an H-film wrap around the tank would preclude this possibility.

KOH cannot be spilled from any of the LM batteries even if the case vents do not function properly, unless there is an accompanying electrical failure. The LM batteries all have vent valves to relieve product gases. If the vent valves were to fail, the primary batteries would relieve through the gasket cover whereas the pyro battery cases would split. In either case there is little possibility of an explosive battery case rupture. The primary battery vent valves are operationally checked just prior to vehicle installation. A similar check should be made on the pyro batteries. There are no data on the burst characteristics of the batteries. These data should be obtained.

j. The Apollo 13 anomalies associated with the descent batteries are being investigated and reported through normal postflight procedures. These anomalies are unresolved at this time.

k. It is impractical to protect the LM against a framentary failure.

8 RECOMMENDATIONS

Based on the results of the LM systems evaluation summarized in Section 2 through 6 and the conclusions presented in Section 7, the following recommendations are submitted for consideration:

- Additional study should be given to wrapping of the gaseous helium tanks with a single layer of H-film to preclude KOH attack and reduce the effects of direct solar heating
- The pyro battery activation procedure should be modified to include vent valve checkout
- Burst tests of all batteries should be conducted
- The requirement for the APS PLD's should be investigated further, and the units should be removed or inerted if found to be unnecessary
- Additional materials testing should be conducted in those areas where a general lack of engineering data has been discovered.

  Specifically, the following tests should be conducted:

  a. GOX impact tests of all LM O_2 system impact applications including consideration of single point failures.

  b. Combustion and ignition tests of appropriate LM materials in N_2O_4 and A-50 to verify analytical conclusions of this study.

  c. Impact tests of all nonmetallic materials in LM N_2O_4 and A-50 impact applications.

  d. Conduct present standard O_2 flash and fire test at elevated pressures to verify the applicability of existing ambient data.
- Present materials controls should be broadened to assure MSC surveillance of all materials requirements and applications in all areas of the spacecraft.
- Intentional fault tests should be conducted in all spacecraft components where combustion is possible to assure adequate design margins and circuit protection.